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FUSIBLE HEAT SINK FOR EVA THERMAL CONTROL

FINAL REPORT

BY

GEORGE J. ROEBELEN, JR.

PREPARED UNDER CONTRACT NO. NAS 2-8912
BY
HAMILTON STANDARD
DIVISION OF UNITED TECHNOLOGIES CORPORATION
WINDSOR LOCKS, CONNECTICUT 06096

FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER
MOFFETT FIELD, CALIFORNIA 94035

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CR 137769
SVHSER 6821

FOREWORD

This report has been prepared by the Hamilton Standard Division of United Technologies Corporation for the National Aeronautics and Space Administration, Ames Research Center in accordance with the requirements of Contract NAS 2-8912, Fusible Heat Sink for EVA Thermal Control.

Appreciation is expressed to the NASA Technical Manager, Mr. Bruce Webbon of the Ames Reseach Center, for his guidance and advice.

Hamilton Standard personnel responsible for the conduct of this program were Mr. Daniel J. Lizdas, Project Manager and Mr. George J. Roebelen, Jr., Program Engineer. Appreciation is expressed to Mr. John S. Lovell, Chief, Advanced Engineering, Mr. Earl K. Moore, Technical Specialist, Mr. W. Clark Dean, II, Design Engineer, Mr. Edward H. Tepper, Analytical Engineer, and Mr. Gerald Winter, Analytical Engineer, whose efforts made the successful completion of this program possible.

Hardware concept drawings have been prepared as a result of effort expended during the period covered by this report. These drawings, Fusible Heat Sink System - Packaging Concept, SVSK 91745 Sheet 1 and 2, and Fusible Heat Sink System - Heat Exchanger Concept, SVSK 91780, have been transmitted under separate cover.

INTRODUCTION

Future manned space exploration missions are expected to include requirements for astronaut life support equipment capable of repeated use and regeneration for many extravehicular activity (EVA) sorties. In anticipation of these requirements, NASA/ARC funded two contracts (NAS 2-6021 and NAS 2-6022) for the study of Advanced Extravehicular Protective Systems (AEPS). The purpose of these studies was to determine the most practical and promising concepts for manned space flight operations projected for the late 1970's and 1980's and to identify areas where concentrated research would be most effective in the development of these concepts.

One regenerative concept for astronaut cooling utilizes a fusible slurry pack as the primary heat sink for a liquid cooling garment (LCG) cooling system. A solution of potassium bifluoride in water, developed under NASA/ARC Contract NAS 2-7011, is employed as the major constituent in the slurry.

This report describes the effort funded by NASA/ARC under Contract NAS 2-8912 during which a heat sink system utilizing a phase change slurry material was preliminary designed and analyzed, and candidate phase change slurry materials were evaluated.

SUMMARY

The objective of the Fusible Heat Sink for EVA Thermal Control program is to evaluate candidate phase change slurry materials and to preliminarily design and analyze a heat sink system utilizing a phase change slurry material to be used eventually for astonaut cooling during manned space missions.

A fusible material investigation was conducted to develop a suitable slurry mixture for the fusible heat sink application and to test the critical properties of the fusible material in a simulated system. This investigation has demonstrated that a slurry with the composition of 45 ml of 30 g potassium bifluoride per 100 g water solution combined with 5 ml of ethanol provides the desired thermal storage capacity and slurrying properties required for satisfactory fusible heat sink operation.

Utilizing the selected slurry material, a preliminary design was concepted for the fusible heat sink system, and an extensive math model was written to describe the thermal operation of the system during normal (astronaut cooling) and recharge (refreeze) conditions. The output from the math model verifies the desired thermal gradients necessary for fusible heat sink operation. Hardware drawings have been prepared describing the fusible heat sink concept. These drawings, Fusible Heat Sink System - Packaging Concept, SVSK 91745 Sheet 1 and 2, and Fusible Heat Sink System - Heat Exchanger Concept, SVSK 91780, have been transmitted under separate cover.

Based on the results of this program, the Fusible Heat Sink for EVA Thermal Control has been demonstrated to be an acceptable concept for EVA Thermal Control.

CONCLUSIONS

It is concluded that a slurry of potassium bifluoride/water/ethanol meets all requirements for a regenerable heat sink material and that a system can be designed to perform satisfactorily using this material.

RECOMMENDATIONS

The studies and test results of this program have indicated that a slurry system can be designed to satisfy the Fusible Heat Sink for EVA Thermal Control requirements. Therefore, it is recommended that a laboratory demonstration module aimed at demonstrating the feasibility of the concept generated by this program be designed, analyzed, manufactured, and tested.

NOMENCLATURE

Btu	British thermal unit
Btu/hr	British thermal unit per hour
Btu/hr-ft-°F	British thermal unit per hour-foot-degree Fahrenheit
Btu/hr-ft^2-°F	British thermal unit per hour-square foot-degree Fahrenheit
Btu/lb-°F	British thermal unit per pound-degree Fahrenheit
cal	calorie
cal/g	calorie per gram
cm	centimeter
°C	degree Celsius
DC	direct current
EVA	extravehicular activity
ft	foot
°F	degree Fahrenheit
g	gram
g/s	gram per second
HX, H/X	heat exchanger
H_2O	water
in	inch
J	joule
J/g	joule per gram
J/g-°C	joule per gram-degree Celsius
J/s	joule per second
J/s-m-°C	joule per second-meter-degree Celsius
kg	kilogram
kg/hr	kilogram per hour
KHF_2	potassium bifluoride
kJ	kilojoule
kJ/hr	kilojoule per hour
kPa	kilopascal (kilonewton per square meter)

NOMENCLATURE (Continued)

lb	pound
lb/hr	pound per hour
lb/min	pound per minute
LCG	liquid cooling garment
LSS	life support system
m	meter
mc_p	thermal mass
min	minute
ml	milliliter
NPT	national pipe thread
O.D.	outside diameter
Pa	pascal (newton per square meter)
PLSS	portable life support system
psi	pound per square inch
psia	pound per square inch absolute
T.C.	thermocouple
T_1, T_2, T_3, T_4	temperature
VDC	direct current volt
W	watt
W/cm-°C	watt per centimeter-degree Celsius
W/cm^2-°C	watt per square centimeter-degree Celsius
W_1, W_3, W_5	flow rate
ΣG	sum of conductances to adjacent parts

The Fusible Heat Sink for EVA Thermal Control program was performed in four phases. These phases are discussed in the following sections:

Fusible Materials Investigation

Preliminary Design

Performance Analysis

Component and System Specifications

FUSIBLE MATERIAL INVESTIGATION

Based on the results of the Thermal Storage Materials effort conducted under NASA/ARC Contract NAS 2-7011, the phase change material was selected at the inception of this Fusible Heat Sink program. A slurry containing a thermal storage solution of 30 grams potassium bifluroide (KHF_2) per 100 grams of water mixed with a suitable slurrying admixture will be developed. Following is a description of the effort associated with this task.

SLURRY EVALUATION

In order to evaluate the suitability of a particular slurry for our specific application, the following list of required characteristics has been established:

Relatively high thermal absorption capability

Absorption capability in temperature range of -15°C to 0°C

Pumpable when "frozen"

Low toxicity of vapor at room temperature and pressure

Three categories of mixtures were selected for initial investigation; all satisfy the vapor toxicity requirement. The relatively low level of ethanol could be mildly exhilarating but not toxic.

30g KHF_2 per 100g H_2O

30g KHF_2 per 100g H_2O, ethylene glycol admixture

30g KHF_2 per 100g H_2O, ethanol admixture

Six 50 ml specimens were prepared and capped in Lexan centrifuge tubes of 0.10 cm wall thickness and 2.65 cm internal diameter:

Sample #1	50 ml of 30g KHF_2/100g H_2O
Sample #2	47.5 ml of 30g KHF_2/100g H_2O 2.5 ml of ethylene glycol
Sample #3	45 ml of 30g KHF_2/100g H_2O 5 ml of ethylene glycol
Sample #4	47.5 ml of 30g KHF_2/100g H_2O 2.5 ml of ethanol

Sample #5	45 ml of 30g KHF_2/100g H_2O 5 ml of ethanol
Sample #6	40 ml of 30g KHF_2/100g H_2O 10 ml of ethanol

Each of the six specimens was cooled a minimum of 3 times each to final temperatures of -17.8°C (0°F), -15°C (5°F), and -12.2°C (10°F).

Samples 1, 2, and 3 were solid at each of the three final temperatures of -17.8°C (0°F), -15°C (5°F), and -12.2°C (10°F) and were judged unacceptable as slurry materials.

Samples 4, 5, and 6 all exhibited a slurrying effect where the outer portions of the mixture, the part that "froze" first, were relatively solid, and the inner core remained liquid/slushy. The only immediately noticeable difference between the three samples was that the size of the core was directly related to the ethanol content. The fact that the inner portion of the specimen remained liquid leads us to conclude that the proper approach is to package the system such that the fluid contained in the pump and associated lines is the last to chill and, hence, remains liquid. Proper location of components and insulation panels can accomplish this desired slush distribution. The liquid portion flows around the periphery of the frozen portion, gradually thawing the entire slurry.

During several cooling runs, Sample #6 failed to solidify at a temperature of -17.8°C (0°F). Rapid agitation of the sample produced a crystallization that was thought to be freezing of the fluid. However, further investigation indicated that the freezing point of the 20% ethanol slurry is in the -17.8°C (0°F) range, thereby accounting for the occasional failure to solidify. The solubility of KHF_2 in H_2O in this temperature range is approximately 8g per 100g H_2O. Apparently, the precipitate that occurred during agitation of the unfrozen sample was KHF_2 rather than ice crystals. A description of process by which the freezing point and concentration properties were obtained is contained in the System Simulation Testing section following.

An assessment of the properties of the six samples tested indicates that Sample #4 (5% ethanol) and Sample #5 (10% ethanol) exhibit the characteristics required for satisfactory performance in our application. The significant differences between Sample #4 and Sample #5 are: Sample #4 (5% ethanol) would be expected to have a slightly greater heat absorptive capability per unit volume due to its lesser volume of ethanol, and Sample #5 (10% ethanol) has been observed to have a larger liquid center in the

frozen condition. Inasmuch as the Fusible Heat Sink concept depends on the slurry having a liquid center for start up conditions, it was decided to follow the conservative approach and select the 10% ethanol slurry for further investigation. Once the feasibility of this concept has been proven, additional effort could be expended to study the possibility of reducing the slurry ethanol content.

It was decided to utilize the United Technologies Research Center, the agency that performed the Thermal Storage Materials effort under Contract NAS 2-7011, to perform calorimeter testing of the 10% ethanol specimen to ensure that the addition of ethanol to the KHF_2/H_2O solution did not alter the manner in which the KHF_2 precipitated during freezing and, hence, degrade the heat absorptive capability of the potential slurry material. Figure 1 illustrates the results of this calorimeter testing. As shown, the 10% ethanol specimen produced a heat absorption of 487 J/g (116.4 cal/g) as compared to a predicted value of 456.3 J/g (109.1 cal/g) (90% of the 507 J/g (121.2 cal/g) obtained during previous testing of the 30g KHF_2/100g H_2O solution). The specific gravity of the 10% ethanol specimen was measured as 1.10 at 21.1°C (70°F). Therefore, the heat absorption per unit volume of the 10% ethanol specimen is approximately 535.7 J/cm^3 (8.32 Btu/in^3). These values of heat absorption are as expected and are acceptable for Fusible Heat Sink slurry.

A cooling curve was run on the 10% ethanol specimen to determine the temperature range over which the bulk of the heat was absorbed. This curve is obtained by freezing the specimen and allowing it to thaw at room temperature. Specimen temperature vs. time is ploted in Figure 2 which shows that the majority of heat absorption has been completed by the time the specimen reached -5°C (23°F).

An experiment was conducted to determine the volume increase of the 10% ethanol slurry during freezing. A quantity of 20 ml of liquid slurry was placed in a graduated cylinder and frozen. The frozen slurry volume was measured at 20.9 ml $\pm$ 0.1 ml. This translates into a volume increase during freezing of 4 to 5%.

The 10% ethanol specimen satisfies all of the established slurry requirements; system simulation testing was conducted using this solution.

SYSTEM SIMULATION TESTING

The object of conducting system simulation testing is to verify satisfactory performance of the selected slurry when subjected to conditions encountered during actual system operation.

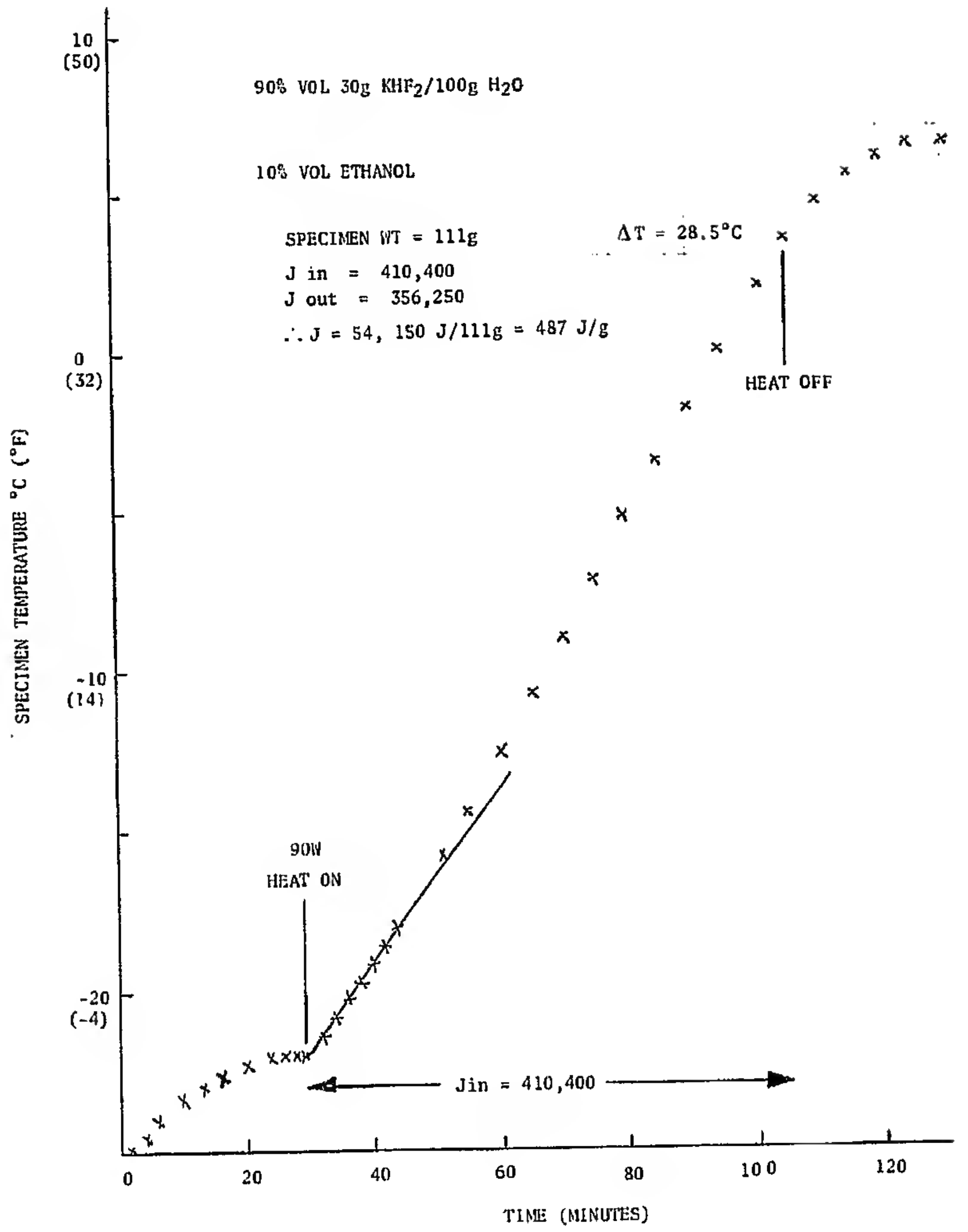


FIGURE 1: CALORIMETER TEST CURVE

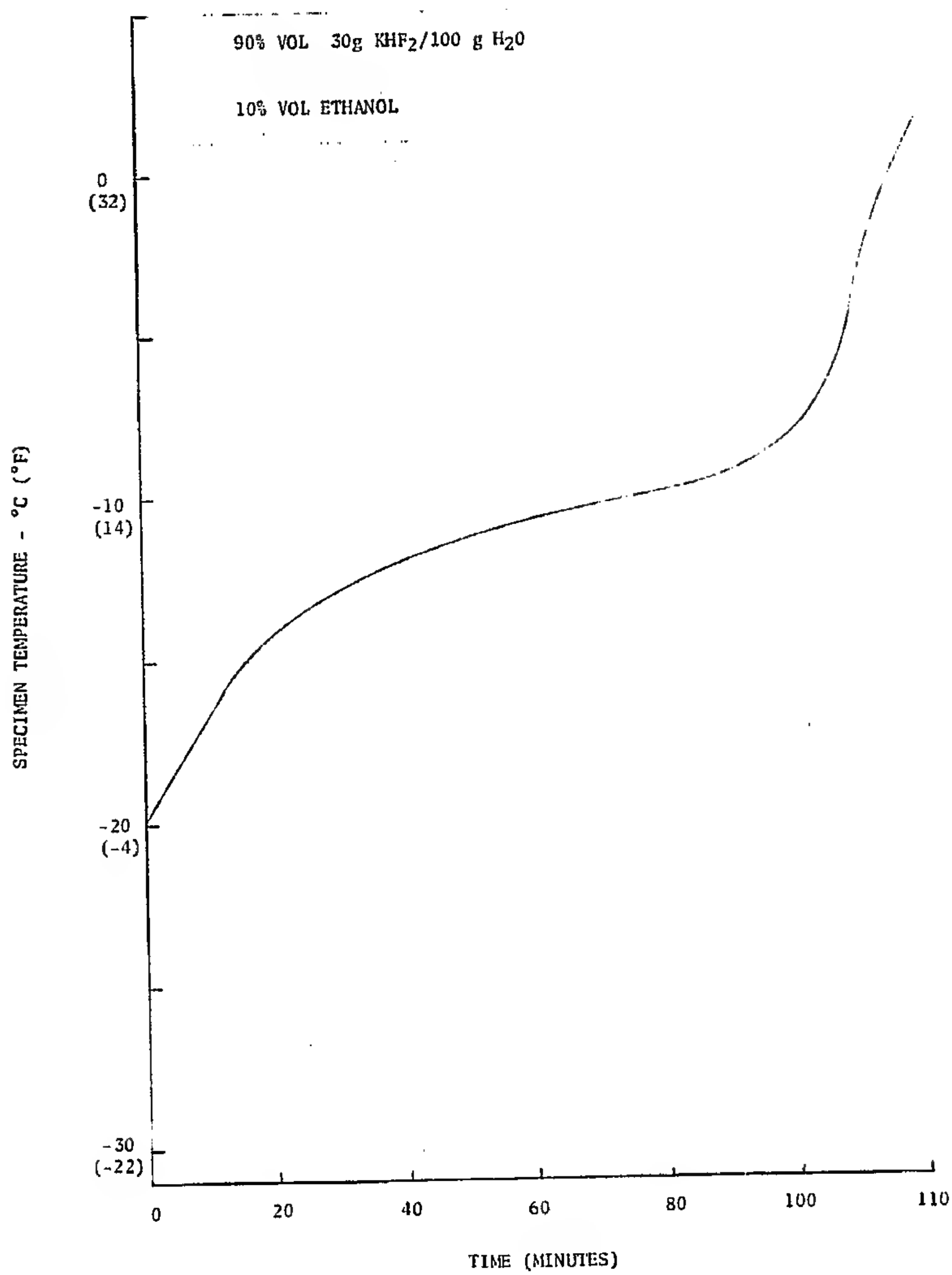
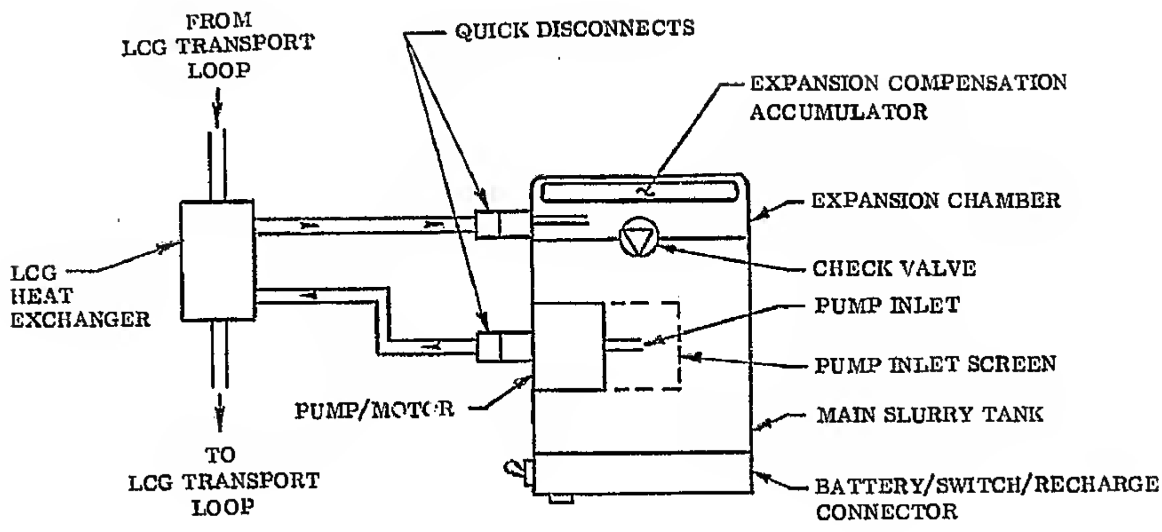


FIGURE 2: COOLING CURVE

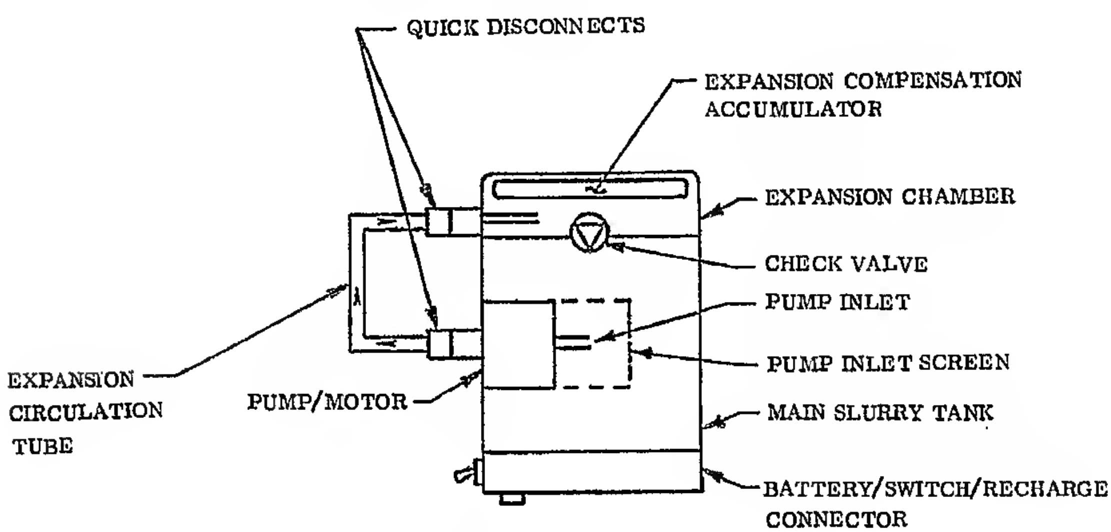
The system concept, described in the following paragraphs, contains a suitable amount of slurry that is "frozen" in preparation for usage. During usage, the liquid portion of the slurry is pumped from the slurry storage tank through the LCG heat exchanger where heat is absorbed from the LCG cooling loop, and back to the slurry tank. When the entire slurry is "thawed" by contact between the liquid portion of the slurry and the frozen slurry interface, the system is removed from the LCG heat exchanger interface and returned to the freezer for recharge (refreezing, etc.). The problem to be solved revolves around demonstrating that the system can, in fact, be configured in a manner that locates the liquid portion of the "frozen" slurry in the required location. Specifically, there must be liquid slurry in the pump, interconnecting lines, and LCG heat exchanger quick disconnects at all times to allow slurry circulation when the slurry has been "frozen".

The configuration selected by Hamilton Standard, shown in Figure 3, incorporates a main slurry tank and an expansion chamber interconnected by a check valve. During normal operation, the slurry flows from the main slurry tank, through the pump inlet screen, through the pump, out the outlet quick disconnect, through the LCG heat exchanger, in the inlet quick disconnect, through the expansion chamber, and through the check valve back to the main slurry tank. In this manner, the slurry stream removes heat from the LCG heat exchanger and absorbs it within the slurry, thereby melting the slurry and redissolving the KHF_2 in the H_2O solvent. (KHF_2 has a negative heat of solution with H_2O, thereby, heat is absorbed during mixing.)

Recharge is accomplished by disconnecting the LCG heat exchanger from the system at the quick disconnects and connecting the expansion circulation tube to these quick disconnects as shown in Figure 3. The system with the expansion circulation tube attached is placed in a -15°C (5°F) freezer for chilling. The system insulation during recharge is arranged to allow easy heat transfer through the main slurry tank and to resist heat flow through the expansion circulation tube, the quick disconnects, and the expansion chamber. With this configuration, the slurry in the main slurry tank will cool more rapidly than the fluid in the insulated area and, hence, will start to freeze first. As the slurry in the main slurry tank freezes at external surfaces, it expands, forcing liquid slurry from the unfrozen center through the insulated expansion circulation tube and into the expansion chamber. The check valve prevents flow directly from the main slurry tank to the expansion chamber. As the slurry starts to freeze, the H_2O becomes ice and the KHF_2 precipitates. The ethanol separates from the freezing mass and remains liquid, thereby increasing the ethanol content of the unfrozen portion until the concentration point where the slurry will not freeze is reached.



NORMAL OPERATION



RECHARGE

FIGURE 3: FUSIBLE HEAT SINK SCHEMATIC

All this time, the liquid slurry with increasing ethanol content is being forced through the expansion circulation tube by the expansion of the freezing slurry in the main slurry tank. A small externally powered electric heater supplies heat to the expansion circulation tube to prevent it from freezing before the ethanol content has reached sufficient concentration to inhibit freezing. At the point where the entire system is chilled to -15°C (5°F), the liquid slurry is strategically located in the pump, quick disconnects, expansion circulation tube, and other central areas where it allows a flow path when the pump is energized. The system is made ready for use by buttoning up the insulation around the main slurry tank, removing the expansion circulation tube and electrical connector, and connecting the unit to the LCG heat exchanger.

A system simulator module was constructed, as shown in Figure 4, with thermocouples located as shown. Figure 5 shows the module with the LCG heat exchanger simulator attached to the multipoint recorder, and Figure 6 shows the module in the -15°C (5°F) freezer.

Thermal insulation was applied to the expansion chamber, the motor and magnetic drive, and the expansion circulation tube. A section of heater tape was wrapped along the expansion circulation tube because the resistance paths of the simulator were not representative of the thermal paths that will be encountered in the actual system design. Specifically, the plexiglass wall used in the main slurry tank for visibility presents a significantly greater thermal resistance than a metal wall. Conversely, the relatively bulky configuration of the expansion circulation tube and quick disconnects on the module present a significantly lower thermal resistance compared to the anticipated well insulated expansion circulation tube design. The intent was to use the 10 watt heater intermittently to keep the expansion circulation tube temperature from falling faster than the main slurry tank temperature and prevent the tube from freezing prematurely. It is estimated that less than 1 W will be required for the actual Fusible Heat Sink configuration. No heat was applied after the system reached -5°C (23°F) which is slightly above the freezing point of the slurry per Figure 2. The actual system is designed, and the math model thermally verifies that the 1 W is sufficient to insure that the expansion compensation tube temperatures does not cool more rapidly than the main slurry tank.

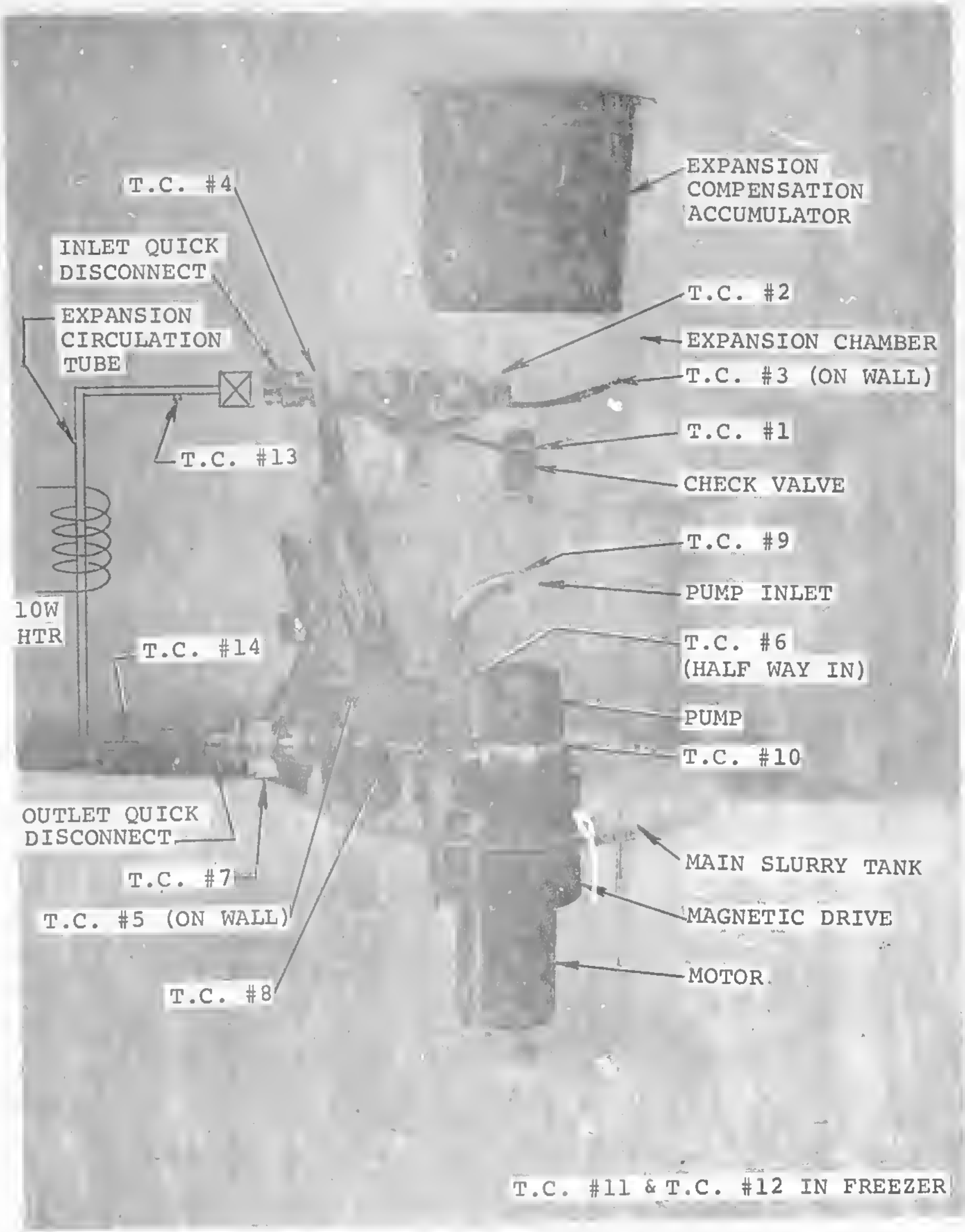


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FIGURE 4: SYSTEM SIMULATOR MODULE

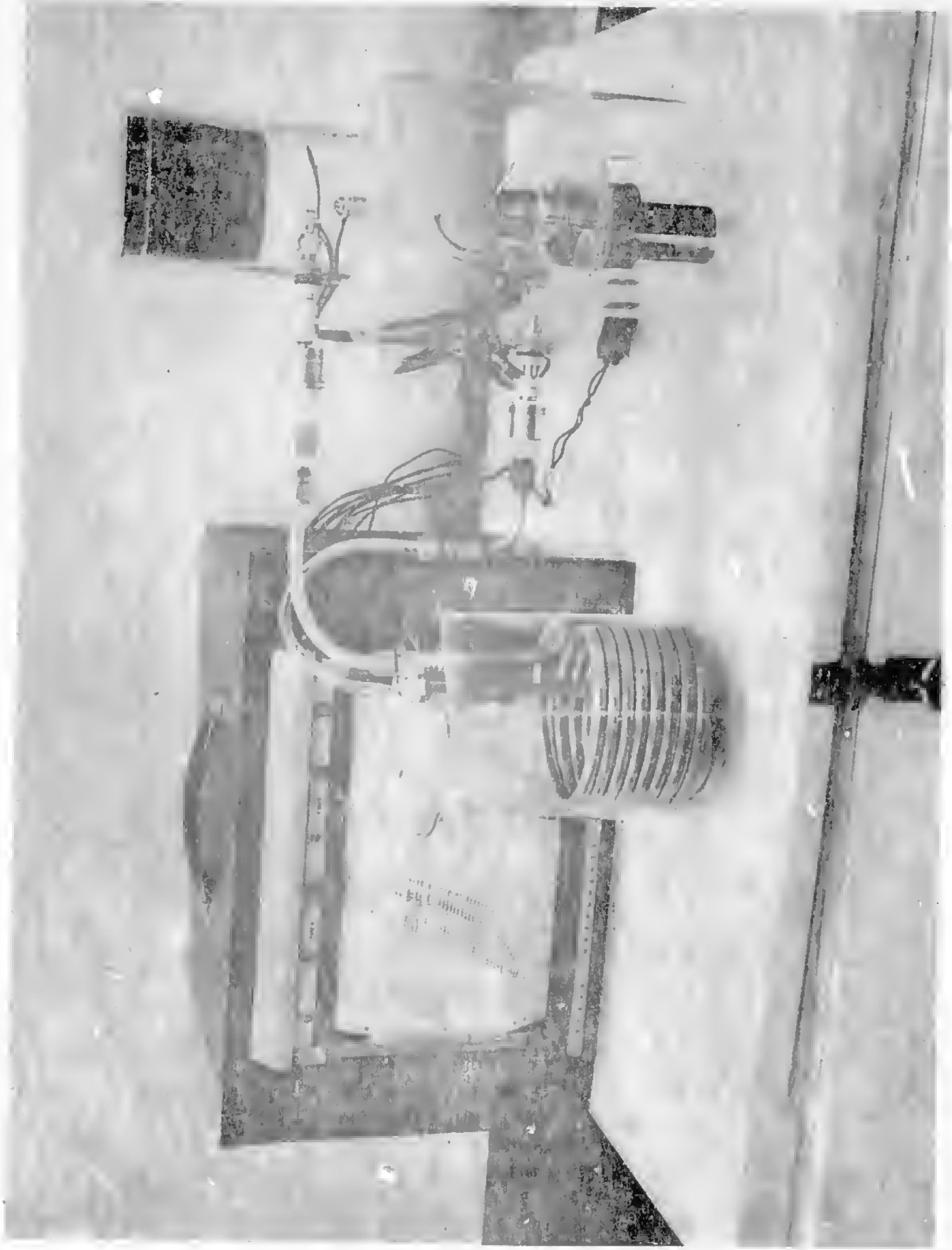

FIGURE 5: MODULE AND INSTRUMENTATION

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FIGURE 6: FREEZER INSTALLATION

The system simulator module with the expansion circulation tube installed was inserted in the freezer as shown in Figure 6. A circulating fan in the freezer was used to insure uniform temperature throughout the freezer. The multipoint recorder was started, and the temperatures of the fourteen thermocouples located per Figure 4 were recorded. As expected, the temperatures at the expansion circulation tubes (T.C. 9, 10, 13, 14) fell more rapidly than the temperatures in the main slurry tank. The 10 watt heater tape surrounding the expansion circulation tube was energized for 10 minutes per hour for a period of six hours at which time the entire simulator had reached the -5°C (23°F) point where the freezing process starts. From this point on, no heat was applied to the expansion circulation tube. An additional sixteen hours of freezing was applied at which time the simulator had stabilized at approximately -15°C (5°F). The multipoint recorder was turned off and the simulator removed from the freezer for examination. After removal of the insulation, visual examination of the simulator (frost had to be wiped off every minute or so) showed that the liquid portion of the slurry had indeed been pushed from the main slurry tank through the expansion circulation tube, and into the expansion chamber. The expansion compensation accumulator showed significant compression. As best as could be determined visually, liquid slurry was located in the pump area, expansion circulation tube area, and check valve area. Additional proof of the satisfactory operation of the expansion circulation tube was evident in that the main slurry tank was intact; any trapped volume of slurry would have fractured the container. Cold start of the pump/motor was attempted unsuccessfully. This was taken as a motor seize-up because mere stalling of the pump causes the magnetic drive to slip. The motor had been soaked with slurry during simulator loading operation. The pump/motor was disassembled and inspected. Excessive torque was required to rotate the pump shaft. Pump disassembly showed a sludge had become imbedded in the shaft bearings. The cold start problem will be examined further during the follow-on program.

An analysis of the portion of the 10% ethanol slurry remaining liquid after being cooled to -15°C (5°F) shows the breakdown to be 21.5% vol. ethanol and 78.5% vol. KHF_2/H_2O with a KHF_2 concentration of approximately 8g per 100g H_2O. This compares to an original composition of 10% vol. ethanol and 90 vol. KHF_2/H_2O with a KHF_2 concentration of 30g per 100g H_2O. Thus, the original assumption that the KHF_2/H_2O solution fractionally freezes out of the total solution, leaving a concentrated ethanol liquid was verified.

CONCLUSIONS

Based on the results of the slurry evaluation and subsystem simulation testing, it is possible to conclude that the 10% ethanol slurry behaves satisfactorily as anticipated, and the system configuration, using supplementary heat, positions the liquid portion of the slurry in the required positions in the system loop.

This last conclusion is further verified by the Math Model described in the Performance Analysis Section in which the thermal characteristics of normal operation and recharge for the final configuration are analyzed and established.

PRELIMINARY DESIGN

A concept for a preliminary design of a heat sink system utilizing a potassium bifluoride/water/ethanol phase change material has been generated. The following pages describe the selected system and present justification for the system and component selection.

SPECIFICATION, FUSIBLE HEAT SINK SYSTEM

Non-venting, non-umbilical.

Separable from the primary LSS with the only scar being the quick-disconnects. The liquid/liquid heat exchanger remains with the primary LSS.

Self-contained with its own power source, pump, and accumulator.

2,110 kJ (2,000 Btu) capacity.

10°C (50°F) LCG cooling loop temperature capability.

Fusible mode only, i.e., no evaporation at any time.

Control of heat rejection will be accomplished by varying flow parameters in the LCG loop with the fusible system loop operating with steady flow.

Heat sink to be replaceable in vacuum by one man if additional capacity is required to extend duration.

Heat Rejection Rates

Minimum - 117 J/s (400 Btu/hr)
Average - 440 J/s (1,500 Btu/hr)
Maximum - 586 J/s (2,000 Btu/hr)

Duty Cycle

One regeneration/usage per 24 hours
System capability goal 100 regenerations

Vehicle Interfaces

Freezing/storage provisions - as required by system
Power penalties - not available

RECOMMENDED SYSTEM

Figure 3 shows the schematic relationship of the components in the recommended Fusible Heat Sink System. Normal operation and recharge of this system was briefly described in the previous section. Components of the system are immersed in the slurry tank to maximize packing density and, hence, minimize the total package volume. A partition separates the main slurry tank containing the pump/motor from the remainder of the tank containing the battery and the expansion compensation accumulator. Volume changes of the liquid caused by melting ice is compensated for by the air filled rubber bladder accumulator in this section. A check valve is located in the partition to allow flow from the accumulator section into the main section while preventing reverse flow during recharge. Flow from the check valve is directed through a tube that distributes the return flow uniformly through the slurry tank, thus preventing channeling. The pump outlet is delivered through a zero spill, self-sealing, quick disconnect to the LCG heat exchanger located in the LCG transport loop. After cooling the LCG transport loop, the fluid returns to the accumulator section of the slurry tank through a second disconnect. The fluid then flows through the check valve and distribution tube into the pump section of the slurry tank and through a screen into the pump inlet. The screen prevents large chunks of ice that could stall the pump from entering the pump inlet. Figure 7 shows the packaging arrangement of the system.

After all the ice has melted, the unit must be recharged for reuse. A portion of the insulation blanket that covers the unit during use is removed from the slurry tank walls to speed the freeze up process. The insulation that remains covers the top of the tank, the side of the tank in the accumulator area, and a portion of the side of the tank where the pump is closest to the wall. This selective insulation technique guarantees the proper rate of heat transfer with the result that the center of the slurry tank in the area of the pump inlet is the last to freeze, assuring a high ethanol content there at the completion of the freeze up cycle. A special electrically heated section of insulated pipe containing mating halves of the disconnects is connected to the unit to act as an expansion circulation tube. Refer to Figure 3. It is necessary to heat this tube during the freeze up cycle due to the low thermal mass of the fluid contained in the tube. External power of less than 1 watt will be used by the heater. The unit is then placed in a freezer and cooled to -15°C (5°F). As the fluid cools, ice crystals will form in the main slurry tank increasing the volume of the mixture. Since the check valve prevents reverse flow from the main section of the

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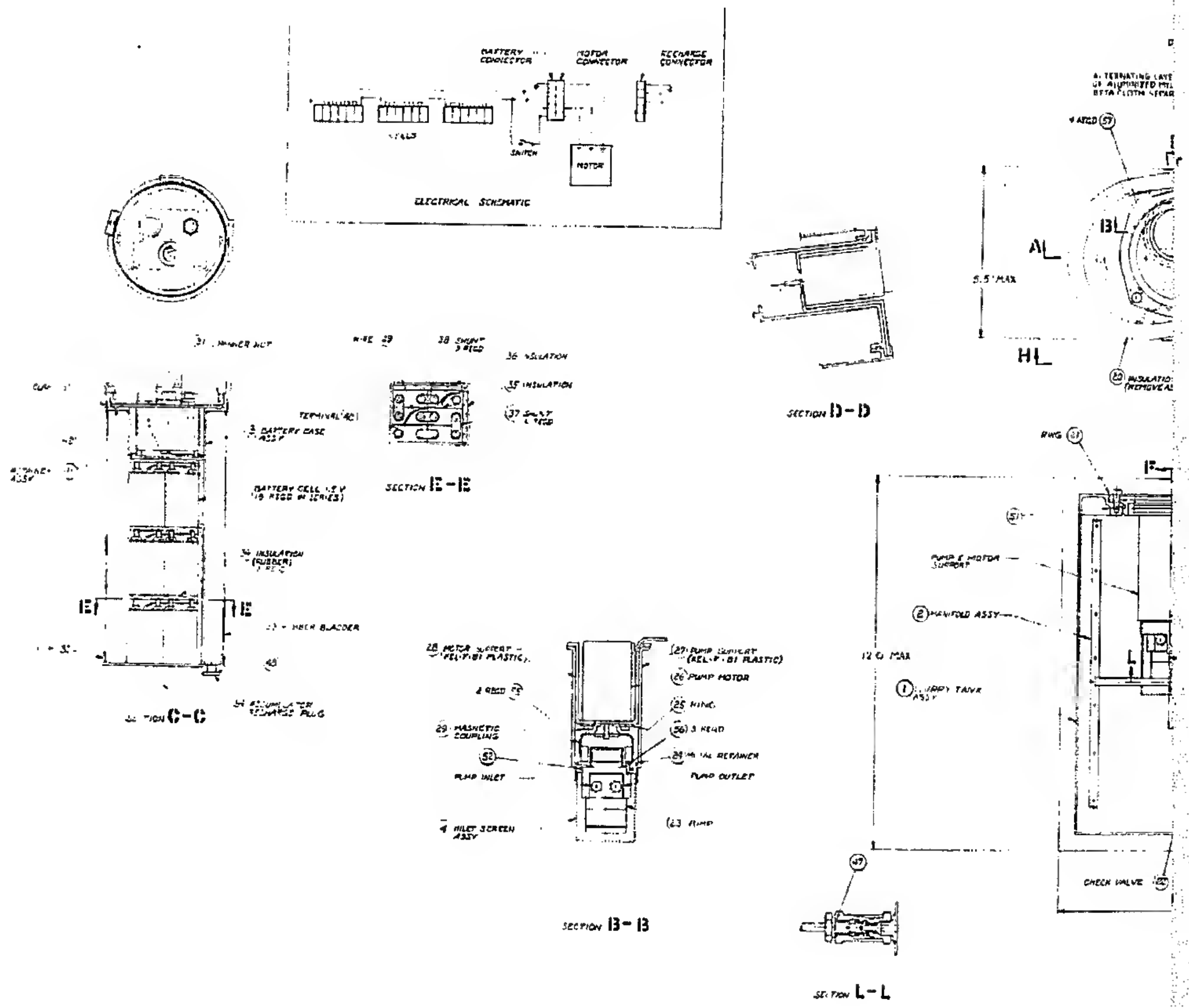

FOLDOUT FRAME

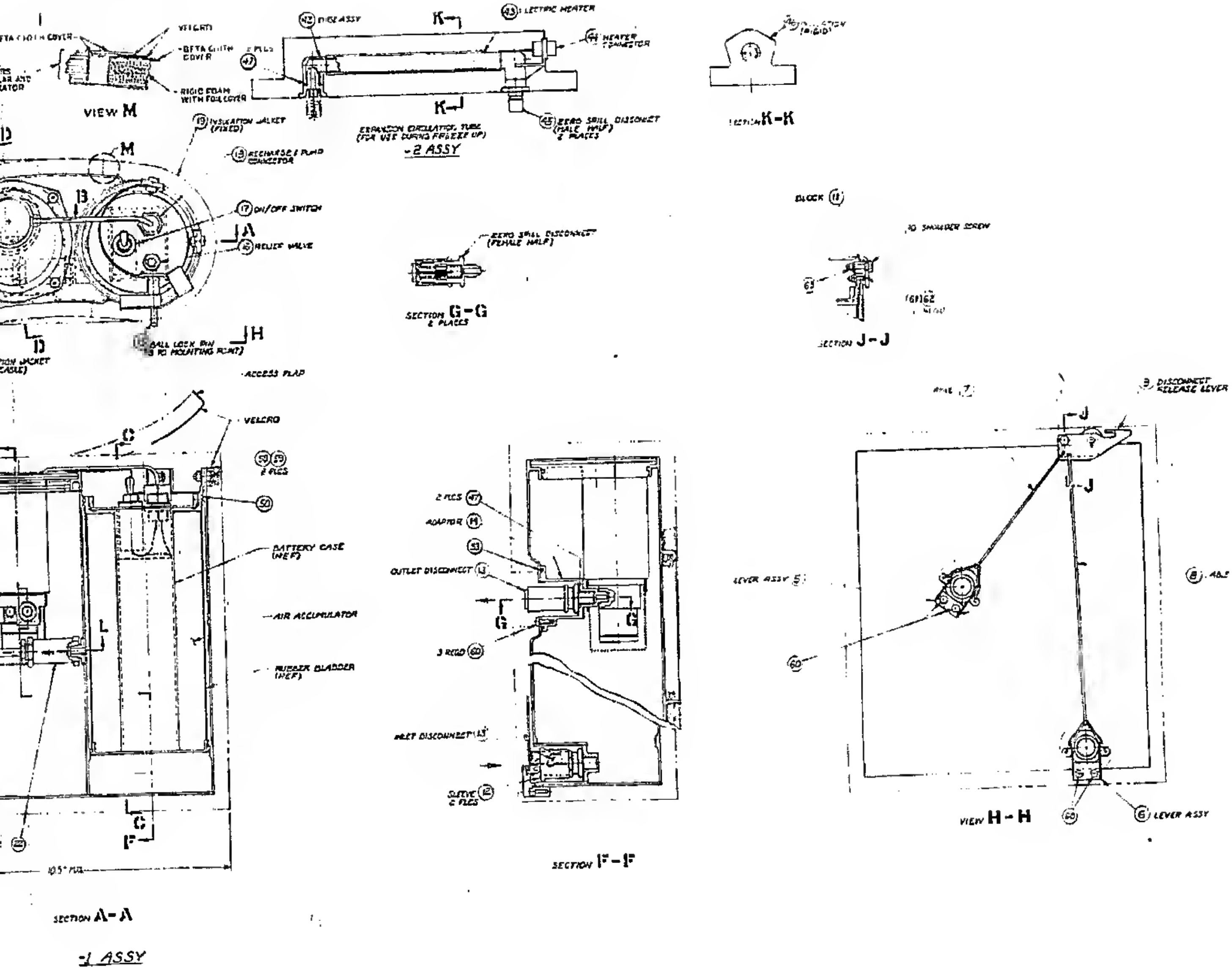

FIGURE 7 : FUSIBLE HEAT SINK SYSTEM CONCEPT

FOLDOUT FRAME 2

slurry tank through the partition to the accumulator section, liquid is forced through the screen, pump, disconnects, and the expansion circulation tube to reach the accumulator section where the volume increase can be accommodated. This process has the effect of assuring that ethanol which is concentrated in the center of the tank as the slurry freezes is present in the pump and disconnects at the completion of the freeze up cycle, thus assuring their proper operation when the expansion circulation tube is removed and the unit is put in service. Concentration of ethanol also occurs in the check valve due to the progressive freeze up of the fluid in the distribution tube with the check valve located in the last to freeze area.

The battery is charged concurrently with the freeze up operation using pins of the same connector that delivers battery power to the pump/motor during unit operation. This connector, as well as an on-off switch and battery pressure relief valve, are located in a recess at the top of the unit and are accessible through a flap in the insulation cover.

Once the unit is frozen and is ready to be used, mechanical attachment to the suit is achieved by utilizing the two quick disconnects as two points of a 3-point mounting system; the third point being a ball lock pin. Removal of the ball lock pin allows actuation of a disconnect release lever. The pin and the lever are both located in the recess on the top of the unit. When the lever is pulled, two separate rods attached to the lever operate cams at each disconnect that depress the ball retaining sleeve of the disconnect allowing separation of the mated halves of the disconnect. During installation, the lever need not be actuated since a push on the unit will connect the disconnects. Inserting the ball lock pin completes the installation and prevents accidental release of the disconnects.

The recommended system excluding the LCG heat exchanger is 30.5 cm (12 in) high, 26.7 cm (10.5 in) wide, and 14.0 cm (5.5 in) deep (see Figure 7) and weighs 10.52 kg (23.19 lb) wet. During the battery charging period of 10 hours, 2.8 watts of power will be required for the battery. One watt will be required for the tube heater during the 24 hour freeze up period.

The recommended LCG heat exchanger is 3.6 cm (1.4 in) deep, 17.8 cm (7.0 in) long, and 16.0 cm (6.3 in) wide with a 17.8 cm (7.0 in) x 12.2 cm (4.8 in) x 0.76 cm (0.3 in) basic core. The heat exchanger weighs 1.56 kg (3.45 lb) wet.

A detailed weight summary is included at the end of this section.

SYSTEM SELECTION JUSTIFICATION

The components required for the basic system are:

Pump - to circulate the fluid
Motor - to drive the pump
Source of Electrical Power - to drive the motor
Tank - to hold the slurry
Volume Compensation Drive - to allow expansion and contraction of the fluid
Heat Exchanger - to cool the LCG heat transport loop water
Disconnects - to allow separation of all but the heat exchanger from the LCG for recharging of the unit

Many factors were considered during the system selection process resulting in refinements to the basic system to assure that the final configuration successfully met all the system operation requirements in the smallest, lightest, most adaptable package. A brief discussion of these system considerations follows.

System Design Considerations

The primary consideration in the design of the system was to prevent freezing of the components in the system during the freeze up period thereby assuring proper operation during subsequent use. The two components of primary concern, regardless of configuration, are the pump and the quick disconnects. These components have moving parts that could jam and fail to operate properly if they were allowed to ingest large ice chunks, or if fluid in them froze solid during freeze up. Locating the pump inlet at the center of the slush tank assures a concentration of alcohol present at the inlet when the unit is turned on, but chunks of slush might still be ingested. For this reason, a screen is included at the pump inlet to filter out any ice particles that could lodge in the pump or any small passage downstream. The screen also tends to distribute the flow of fluid to the pump inlet over a large area, thereby preventing channeling that would reduce the efficiency of the unit.

The disconnects are, by necessity, located at the face of the unit and could not be located in the "last to freeze" area to assure ice would not jam their internal parts. An electrical heating element was considered as a thaw out device but would have the undesirable effect of imposing additional battery weight on the system.

An alternate scheme was devised and finally incorporated in the recommended configuration that utilizes a baffle in the slush tank between the main slurry tank containing the pump inlet and the accumulator. During normal operation, return fluid enters the accumulator side of the baffle and then flows through a check valve in the baffle to the main slurry tank. During freeze up,

the check valve prevents liquid flow from entering the accumulator section to relieve volume expansion from ice formation. Instead, the fluid is forced to flow through the pump and through the disconnects which are interconnected by a thermally insulated and heated "expansion circulation tube" into the accumulator section of the slurry tank. This technique results in liquid of high ethanol concentration being present in both connectors and in the pump at the end of the refreeze cycle, thus assuring their proper operation in use.

Consideration was given to the use of power from the battery on the primary LSS as an alternative to the selected self-contained battery configuration. The average mission life of the Fusible Heat Sink is one hour and the primary LSS can be used for seven hours without recharging. It is advantageous to replace the Fusible Heat Sink battery simultaneously with the slurry tank every hour of the EVA rather than carry one big battery capable of supporting the primary LSS and seven Fusible Heat Sink units.

Configuration Considerations

Shape: The structural limitations on overall unit shape are minimum since the pressure buildup in the unit is limited by the accumulator. The chosen shape fits snugly against the chest or thigh and allows use of wall thicknesses that are easy to manufacture and will resist handling damage. It is impractical to manufacture and attach components to the minimum wall thickness a cylindrical shape would allow. In addition, the cylindrical shape is awkward for attaching to the suit since, for a given length, it extends further from the suit than the chosen shape.

Mounting: A mounting configuration utilizing separate mounting feet with alternate attachment means was rejected in favor of utilizing the inherent mechanical retention of the disconnects with a single ball lock pin providing the third mounting point. Since the ball lock pin also secures the disconnect actuation mechanism, the mounting points are thus obtained with no additional weight penalty.

Component Location: The battery/accumulator and the pump/motor are packaged within the slush tank to minimize the total unit volume by allowing the fluid to conform to and make use of the irregular shapes of these components. External battery and external pump/motor/battery configurations were considered but resulted in larger overall dimensions.

Corrosion: Materials estimated to provide adequate corrosion resistance to the slurry are utilized in all applications where slurry contact is possible. Effort is currently being expended under Contract NAS 2-8665 to experimentally verify suitable materials for slurry exposure.

COMPONENT SELECTION

Each component of the Fusible Heat Sink has been evaluated to determine which characteristics are critical and which type of component best meets these requirements. With the exception of the brush type DC motor utilized for feasibility and functional system hardware, all components are suitable for flight hardware.

Slurry Tank

The slurry tank is the largest component of the system since it must contain 4.17 kg (9.20 lb) of slurry solution which occupies 0.00377 m^3 (230 in^3). The slurry tank also acts as the major structural member of the system since all of the other components are attached to it. Its shape was discussed in the previous section. Although aluminum was considered as the construction material for the slurry tank to minimize weight, the computer heat transfer effort indicated that the lower conductivity of stainless steel would improve the freeze up mode. Additionally, stainless steel provides satisfactory anti-corrosion properties. Experience gained during the fusible materials investigation portion of this program has indicated that simultaneous existence of aluminum and stainless steel in combination with the slurry produces an insoluble precipitate and causes selective chemical attack to the aluminum. Perhaps coatings can be developed to protect the aluminum, but the more conservative approach is to completely eliminate aluminum from the system.

For these reasons, stainless steel has been selected as the slurry tank material.

Expansion Compensation (Accumulator)

Four types of volume expansion devices were considered for the task of limiting the pressure increase due to expansion/contraction in the system. They are as follows: closed cell foam rubber, spring loaded metal bellows, spring loaded rolling rubber diaphragm, and air filled rubber bladder. The pressure rise in the slush tank to be allowed by the device is 6.9×10^4 Pa (10 psi) over the initial atmospheric pressure in the tank. The minimum pressure in the tank must not drop below 5.5×10^4 Pa absolute (8 psia) to prevent vaporization of the ethanol. The closed cell foam approach has several advantages; it is resistant to damage, it can be molded to any shape, and at room temperature there is no tank pressure differential, minimizing long term leakage of the fluid. However, the spring rate of the closed cell foam is higher than an air filled bladder, requiring a larger

accumulator to accommodate the same fluid volume increase for a given pressure rise. The spring loaded metal bellows configuration has a high spring rate and exerts a constant 6.9 x 10 Pa (10 psi) pressure on the system during room temperature storage leading to potential leakage. In addition, ice crystals that become lodged in the convolutions of the bellows will cause a significant increase in bellows spring rate that could cause a system overpressure or premature bellows failure. The spring loaded rolling diaphragm has a lower spring rate and is less sensitive to ice crystals than the metal bellows technique but is still big and heavy when compared to the air bladder technique.

The chosen expansion compensation device is the air filled rubber bladder which is the lightest and lowest volume approach to the expansion problem. It has been configured to allow the battery to be installed within the bladder, thereby optimizing the volume utilization, insulating the battery from the cold slurry, and preventing leakage of corrosive slurry into the battery case. The bladder contains 820 cm^3 (50 in^3) of air at atmospheric pressure that acts as a spring and limits the pressure rise due to 328 cm^3 (20 in^3) of ice expansion to 6.9×10^4 Pa (10 psi). During room temperature storage, the bladder pressure is equal to atmospheric pressure so no air loss will occur. In operation, the 1.01×10^5 Pa absolute (14.7 psia) charge can drop to approximately 5.5×10^4 Pa absolute (8 psia) due to internal leakage before any performance degradation will occur. The nature of the bladder is such that there is never a significant pressure differential between the fluid and the air so that leakage of air into liquid or liquid into air is not likely.

Battery

The battery chosen for the unit is made up of Yardney silver zinc battery cells of the same type used on the Apollo PLSS and are the obvious selection over other types of cells because of their high power densities (see Table I) and their flight proven reliability. The battery characteristics evaluated for this unit were shape, construction, location, cell arrangement, and other salient features.

The individual cells had to be chosen for the proper current capacity and connected in the proper number and order to produce power compatible with the demand of the pump/motor. Eighteen cells of type HR-1 in series produce 27 volts, allow a one ampere current drain, and provide a 1.75 ampere hour capacity as required in the selected arrangmenet. Several external battery locations were investigated in an attempt to thermally isolate

TABLE I
POWER DENSITIES

Battery Type	Watt-hours/kg (Watt-hours/lb)	Watt-hours/cm^3 (Watt-hours/in^3)
Silver-Zinc	84.0 (38)	0.128 (2.1)
Nickel-Cadmium	28.4 (12.9)	0.085 (1.4)
Lead-Acid	22.0 (10.0)	0.073 (1.2)
Nickel-Iron	20.0 (9)	0.024 (.4)

the battery from the cold slurry to allow optimum battery operation temperature, but these locations tended to use volume inefficiently. Therefore, since an air bladder type accumulator had been chosen, it became apparent that within this air volume would be an excellent battery location because the air provides thermal isolation and allows efficient use of volume. In addition, the battery within the accumulator configuration increased the accumulator diameter requirements to the point where a single cylinder simultaneously serves as part of the slurry tank outer wall, the interior baffle, and as an effective accumulator container. A recess at the top of this cylinder offered an excellent protected location for the battery relief valve, power switch, and electrical connector.

The electrical connector serves the dual purpose of connecting the pump/motor lead wire to the battery and power switch, as well as providing recharge connection points. This technique eliminates the necessity of dual connectors or of wiring the battery and motor together permanently. During battery charging, the motor is disconnected, and reconnected once the charge cycle is completed.

The selected switch is a hermetically sealed microswitch unit. The hermetic seal configuration was chosen to prevent switch arcing from igniting any gases vented from the battery cells. To prevent overpressure of the battery case due to these vented gases, a relief valve similar to that used on the Apollo PLSS battery is included to vent the gases to ambient.

To minimize battery weight and corrosion, the battery case is made of welded thin wall stainless steel. The case is configured to provide the accumulator end plates and to accept a cylindrical rubber bladder shell bonded and clamped in place. A sealed plug in the bottom end plate allows introduction of dry air into the space between the battery and the bladder.

Pump/Motor

Four types of pumps were considered for the fluid transport requirement of the unit: piston, centrifugal, peristaltic, and gear. The piston pump has the potential problem of check valve hang-up on ice particles preventing pressure buildup in the pump. The centrifugal pump being a high speed, low torque type of pump has a similar potential problem of the rotor jamming on a small ice particle, thus stalling the pump. The peristaltic pump has the advantage of isolating the fluid from the moving parts of the pump and motor, thereby eliminating the need for a

magnetic coupling or dynamic seals. However, to provide adequate tube life, the unit must be run at very slow speeds necessitating the use of a motor/gearbox combination and resulting in a large pump size. In addition, the frictional losses in flexing the pump tube results in lower overall pumping efficiency requiring a larger battery and motor.

The gear type pump was finally selected since it is inherently a low speed high torque positive displacement type of pump that is capable of crushing small ice particles without stalling and of developing high system pressures to unplug an area that might become blocked with ice.

Since battery power is to be utilized, a brushless DC type motor is desirable. Various brushless type DC motors have been used for space flight programs, but none are available as low cost standard items. Therefore, to minimize cost, a brush type motor is utilized to drive the pump for the feasibility and functional system hardware. For flight hardware, a brushless DC motor would be used. To prevent leakage of slurry into the motor without the use of a dynamic seal, a magnetic coupling will be utilized. This coupling will slip and allow the motor to continue running and avoid a stall type burnout if the pump should jam.

The motor/coupling/pump combination selected for this design utilizes a commercially available Globe motor magnetically coupled to a Micropump. The pump will be tailored to provide the precise flow required and will have the internal flow pressure control bypass valve removed. The motor/coupling housing will be replaced with separate concentric motor and pump supports that mount the pump and motor to the slurry tank. The pump support also acts to seal the top of the slurry tank and to seal the pump housing, thereby preventing liquid from entering the motor and coupling area. The materials utilized in the Micropump are estimated to be suitable for slurry exposure.

Quick Disconnects

The quick disconnects have severe requirements in that they must pass the cooling fluid potentially containing small ice chips without impeding fluid flow, yet must seal tight and not spill fluid or take in air during separation and reconnection. A commercially available unit meeting these requirements is the Seaton Wilson "zero air" quick disconnect.

The selected disconnects have sufficient strength to act as mounting points for the package, and their ease of operation allows easy installation and removal.

Check Valve

A Circle Seal check valve has been selected for the system. The unit selected is commercially available and has the necessary low cracking pressure and low operational pressure drop. Sensitivity to ice inclusion is not critical in this component since at start up, ethanol and warm fluid from the LCG heat exchanger will pass through the unit. The pump inlet screen limits ice particle size during operation. Reverse sealing is necessary only when the fluid is at room temperature at the start of the refreeze cycle.

Expansion Circulation Tube

The expansion circulation tube is configured to accept the mating halves of the quick disconnects that connect to the slurry tank disconnects during freeze up operations. A resistance heating element imbedded in silicone rubber is bonded to the stainless steel tube to supply one watt of heating to prevent freezing. The connector for the heater is mounted to the tube on a bracket that extends through rigid insulation which completely encloses the tube. The insulation is shaped to allow a firm handhold during installation and removal.

Insulation

There are two types of thermal insulation used on the Fusible Heat Sink package: rigid closed cell foam and multilayer aluminized mylar with Beta Cloth fiberglass separators and covers. The rigid foam, covered with aluminum foil tape to meet fire and outgassing criteria, is selected for use on those portions of the slurry tank that will remain insulated during the freeze up cycle; namely, the wall of the tank in the accumulator area and the portion of the tank wall closest to the pump. It is also used on the expansion circulation tube as previously mentioned. In these applications, it is molded to shape and bonded in place.

The flexible multilayer insulation is fabricated into a two piece cover similar to those used on the Apollo PLSS and OPS. Each piece of the cover will be made up of multiple layers of aluminized mylar and separators enclosed in a Beta Cloth cover and sewn together. The Beta Cloth cover is extended to cover those portions of rigid insulation that are attached to the slurry tank, thereby providing a uniform exterior appearance and minimizing convection leaks. The two parts of the cover include a removable piece that covers the sides and bottom of the slurry tanks and a fixed piece that is attached to the top of the unit to provide motor and battery insulation during freeze up operation while

allowing access to the electrical connection and switch on top of the battery by means of a movable flap. Snaps and velcro hooks and pile are used to attach the flexible insulation to the slurry tank.

Heat Exchanger

The system LCG heat exchanger must be designed to be compatible to all the temperature/flow characteristics shown in Figure 8. A unit sized for the worst case thermal condition (end of melt cycle plus high load) must also function with no permanent freeze up at all other operating points. Actual heat exchanger conductance required for these cases varies by a factor of seven - a unit configured for Case VI would be seven times oversized for Case I. It would be very convenient if the ice layer, as it built up, added the necessary resistance or fouling factor to reduce the initial conductance to desired levels. Ice, however, has a relatively high thermal conductivity, 2.25 J/sec-m-°C (1.3 Btu/hr-ft-°F), and thicknesses required are on the order of 2.54 cm (1 in) or greater - a value more than sufficient to completely block the passages of a small volume, light weight heat exchanger. The unit design must, therefore, be permitted to freeze but configured in a manner to ensure thaw out as thermal load increases.

To meet this end, three stainless steel heat exchanger configurations were evaluated: tube in tube, tube in shell, and plate fin. Supporting calculations are presented in Appendix A.

The tube in the tube configuration is inherently the most reliable since it has the least braze or weld length (only the ends of each tube). It has one serious drawback, however, freeze up. An assembly was sized to meet the thermal requirements of Case VI consisting of a 0.318 cm (0.125 in) tube within a 0.846 cm (0.333 in) tube. The core weight for this configuration is 0.22 kg (0.46 lb).

We have selected a maximum value of 6,880 Pa (1.0 psi) for the LCG pressure drop through the heat sink - a value similar to current Apollo hardware. For the tube in tube configuration, an achieved pressure drop of 1,307 Pa (0.19 psi) will be experienced with one 1.47 m (4.82 ft) length of tubing. This value is well within the design requirement. Freeze up is a severe problem with the inlet tube configuration. At low heat loads, complete pluggage of the passage is predicted, and thaw out is virtually impossible. Thus, this configuration will not satisfy the system requirements.

Case	Heat Load Joule/s (Btu/hr)	T_1 °C (°F)	T_2 °C (°F)	T_3 °C (°F)	T_4 °C (°F)	T_5 °C (°F)	W_1 g/s (lb/min)	W_3 g/s (lb/min)	W_5 g/s (lb/min)	Start/ End
I	117.3 (400)	22 (71.7)	0 (32)	-14.3 (6.2)	-13.3 (8.1)	21.1 (70)	1.29 (.17)	30.2 (4)	30.2 (4)	S
II	117.3 (400)	22 (71.7)	0 (32)	-7.3 (18.8)	-6.3 (20.7)	21.1 (70)	1.29 (.17)	30.2 (4)	30.2 (4)	E
III	440 (1500)	16.8 (62.3)	0 (32)	-14.3 (6.2)	-10.3 (13.5)	13.3 (56)	6.27 (.83)	30.2 (4)	30.2 (4)	S
IV	440 (1500)	16.8 (62.3)	0 (32)	-7.3 (18.8)	-3.3 (26.1)	13.3 (56)	6.27 (.83)	30.2 (4)	30.2 (4)	E
V	586.6 (2000)	14.6 (58.3)	0 (32)	-14.3 (6.2)	-8.9 (15.9)	10.0 (50)	9.83 (1.3)	30.2 (4)	30.2 (4)	S
VI	586.6 (2000)	14.6 (58.3)	10.0 (50)	-7.3 (18.8)	-1.9 (28.5)	10.0 (50)	30.2 (4.0)	30.2 (4)	30.2 (4)	E

Fluid specific heat estimated as 3.6 J/g-°C (0.86 Btu/lb-°F)

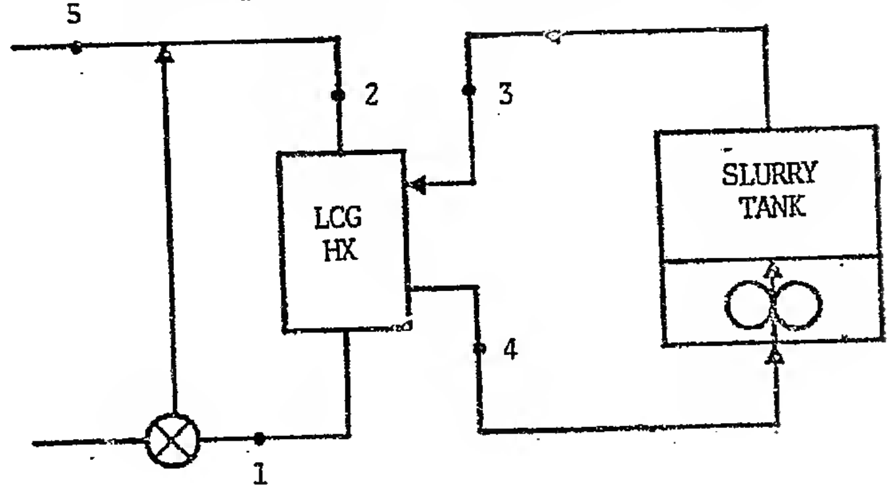

FIGURE 8 SYSTEM TEMPERATURE/FLOW CHARACTERISTICS

Utilizing the standard compact tube and shell configuration, a unit was sized containing 0.318 cm (1/8 in) tubes 4.45 cm (1.75 in) long. The flow is one pass shell and one pass tube side and is contained within a 7.62 cm (2.25 in) O.D. shell. With this concept, tubes will freeze progressively until only that number required to meet low loads (approximately 20 tubes) is still open and passing flow. As heat load increases, however, the cold and frozen tubes surrounded by the slurry solution cannot be thawed. There is no practical manner in which heat can be supplied to these isolated areas to stimulate thaw. The concept, although providing an excellent approach to satisfy the high load requirements, does not appear feasible for a freeze - thaw application. The core weight for this configuration is 0.281 kg (0.63 lb). Pressure drop is less than 700 Pa (0.1 psi).

A plate fin heat exchanger configured to meet the fusible heat sink requirements would be similar to that shown in Figure 9. The concept is a three fluid device containing passages for fusible sink slurry flow, LCG water to be cooled, and heat exchanger LCG bypass flow. Dense, ruffled fins in the main heat exchanger are sized to meet the high load requirements of Case VI (Figure 8). Within the bypass circuit, only the minimum fin density compatible to core structural requirements is employed to minimize heat transfer area. The same criteria will be applied to the fusible sink flow.

At maximum load conditions, the majority of the LCG flow is directed through the heat exchanger with only a minor fraction through the bypass. At minimum load, the condition reversed, and the bypass is handling all or most of the flow. The water in the core freezes under this condition, but that portion of the core adjacent to the bypass remains warm and open to flow. As the heat load increases, flow through the system is diverted to the core, and a thaw out process is initiated. Because all portions of the LCG circuit are adjacent to the warm fluid, the thaw boundary will progress until that portion of the assembly required for heat transfer is available.

The heat exchanger incorporates several features to improve overall system performance. First, the slurry inlet and outlet contain the mating halves of the zero-spill disconnects so that no additional line runs are required, minimizing leakage potential. Second, one of the heat exchanger end plates extends to interface with the EVA suit and seals to the suit pressure bladder, thus providing a suit mounting point for the Fusible Heat Sink. And third, the LCG inlet and outlet ports of the heat exchanger are located inside the suit, and the Fusible Heat Sink inlet and outlet ports are located outside the suit so that no cooling lines need penetrate the suit pressure bladder.

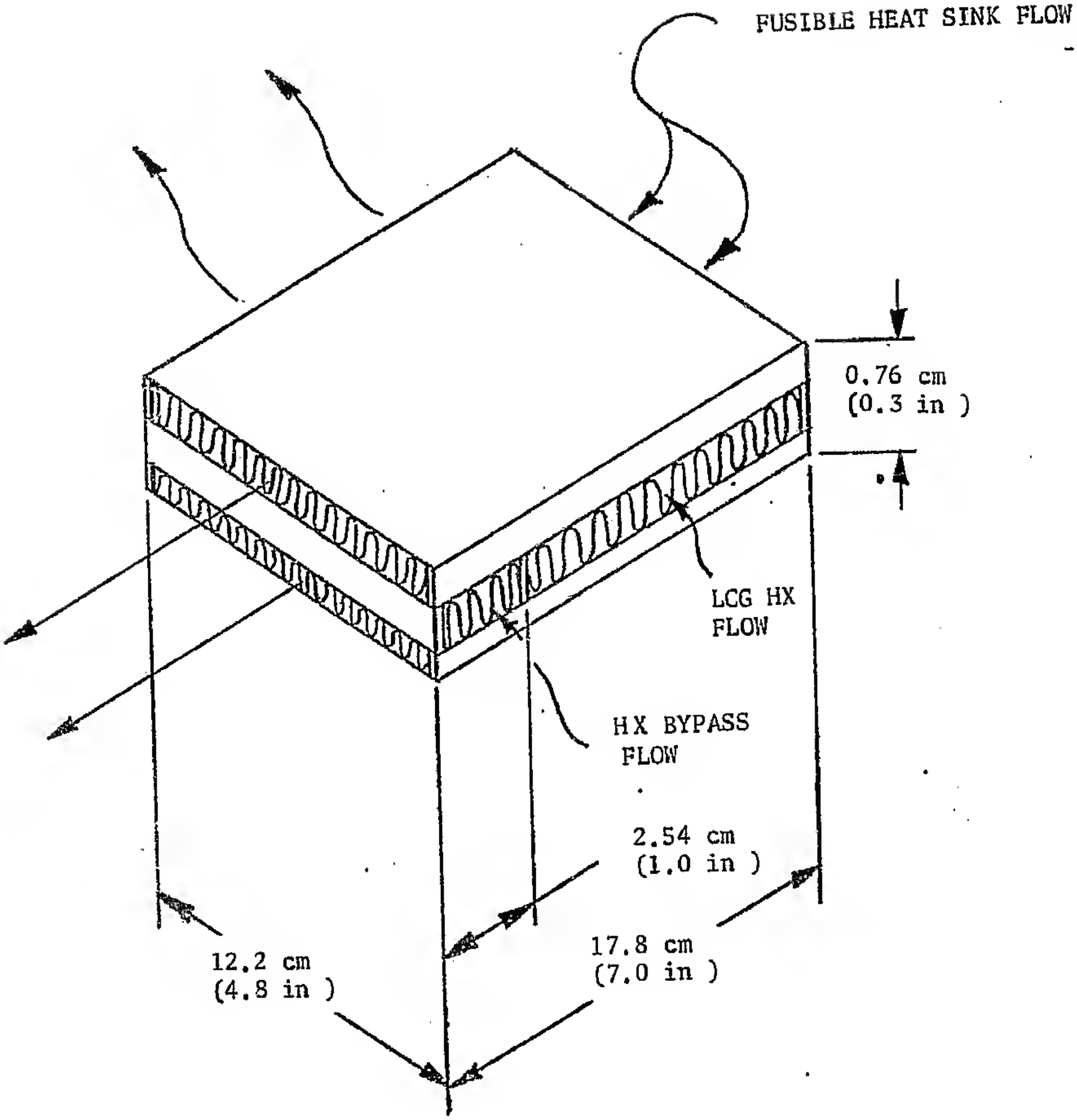

FIGURE 9: PLATE FIN HEAT EXCHANGER CORE

WEIGHT SUMMARY

The weight of every item in the Fusible Heat Sink System has been calculated, measured, or estimated in order to provide as accurate a weight as possible for evaluation of the proposed design concept. As the sample calculations show, each item is broken down into elemental form for an accurate volume calculation and then multipled by the material density to establish a weight. The calculated weight of all items is then totaled. A five percent margin for manufacturing tolerances is then added to account for an approximate two sigma spread on stock thicknesses. This five percent margin has proven accurate in previous calculated item weights. Normally at the concept level of definition of an item, an additional 5 or 10% growth margin would be added to account for possible additions necessary in defining the final layout design weight. However, in the case of the Fusible Heat Sink System concept, the proposed design has been exercised to the point where no additional margin is necessary to predict the weight of the hardware that can be manufactured to this design. This does not preclude the possibility of weight changes to the design, either increases or decreases, that are deemed necessary or desirable after actual hardware testing has been accomplished.

Table II shows a summary of all calculated weights and a total representative of the final design weight of the Fusible Heat Sink. The weights of the Heat Sink, the heat exchanger, and the expansion circulation tube are shown separately since different numbers of each will be carried on board a Shuttle flight. For instance, there will be only as many heat exchangers as there are suits on board. There will be only as many expansion circulation tubes on board as there are Heat Sink spaces in the freezer chest since the tubes are interchangeable between units. Finally, there will be as many Heat Sinks on board as proposed EVA missions require; namely, one Heat Sink per 1.33 EVA man-hours expected to be required in any 30 hour period (24 hour freeze up time plus 6 hours contingency for handling units). Thus, the total flight weight of the Fusible Heat Sink depends on the discretion of the mission planners.

All weights have been calculated in pounds and converted to kg for international units.

TABLE II
CALCULATED WEIGHT SUMMARY

	kg	(lbs)
Fusible Heat Sink		
Slurry Tank	2.37	(5.22)
Battery and Accumulator	1.93	(4.25)
Pump/Motor and Accessories	1.17	(2.58)
Check Valve	0.09	(0.2)
Disconnect Halves	0.17	(0.38)
Disconnect Latch Release	0.38	(0.84)
Thermal Insulation	0.24	(0.52)
Heat Sink Fluid	4.17	(9.20)
TOTAL HEAT SINK WEIGHT	10.52	(23.19)
LCG Heat Exchanger		
Core	0.46	(1.02)
Headers	0.20	(0.45)
Disconnect Halves	0.04	(0.09)
Fluids	0.86	(1.89)
TOTAL HEAT EXCHANGER WEIGHT	1.56	(3.45)
Expansion Circulation Tube		
Tube Assembly and Disconnect Halves	0.10	(0.22)
Heater and Connector	0.04	(0.08)
Insulation	0.05	(0.11)
Fluid	0.17	(0.37)
TOTAL EXPANSION CIRCULATION TUBE WEIGHT	0.36	(0.78)

SAMPLE WEIGHT CALCULATIONS - PUMP/MOTOR

Pump and Motor from Mircopump	
weight = 720 gms x 0.00205 lb/gm	= + 1.587
Less Coupling Enclosure	
67.7 gms x 0.00205 lb/gm	= - 0.139
Plus Screen	
[(π x 1.8 x 2.3 + π x 1.8^2/4) (20 + 20) x π x 0.01^2/4 + π x 1.9 x 0.04 x 0.5] x 0.3	= + 0.050
Plus Disconnect Adaptor	
π (1.65 x 0.5 x 0.18 + 1.2 x 0.08 x 1.0 + 0.8 x 0.4 x 0.13 + 0.5 x 0.1 x 0.5 + 0.25 x 0.1 x 0.4) x 0.3	= + 0.303
Plus Pump Support	
π (2.0 x 4.0 x 0.1 + 3.3 x 0.4 x 0.15 + 3.0 x 1.0 x 0.1) x 0.08	= + 0.326
Plus Motor Support	
π (1.3 x 0.6 x 0.1 + 1.8 x 0.1 x 2.2 + 3.0 x 0.1 x 0.1) x 0.08	= + 0.194
Plus Metal Rings	
π (1.4 x 0.4 x 0.05 + 1.2 x 0.4 x 0.05 x 3.7 x x 0.5 x 0.05) x 0.3	= + 0.136
Total Calculated Weight	2.457
Plus 5% for tolerance	+ .123
Estimated Pump/Motor Weight at Concept Level	2.580 lb

PERFORMANCE ANALYSIS

A math model of the Fusible Heat Sink has been constructed and utilized in support of the preliminary design effort described in the previous section. Specific objectives of the analysis were aimed at describing the sink cool down and thaw out processes to ensure proper functioning during these critical periods.

RECHARGE MODE OPERATION

A study was undertaken to (1) determine the temperature history of the Fusible Heat Sink as it cools to a completely frozen or slurry condition while being refrigerated, and (2) to determine the LCG heat exchanger inlet temperature while fluid is being circulated between the heat exchanger and the Fusible Heat Sink with the LCG heat exchanger absorbing metabolic load.

During cool down and freeze, the Fusible Heat Sink exhibits a net increase in volume accounted for in the design by an expansion compensation device. Expansion in the main reservoir is relieved as fluid or slurry passes through the pump to the expansion circulation tube which discharges into the accumulator. Two factors are utilized to ensure that this flow path remains open during cool down:

- As water is frozen out of solution, the remaining liquid is enriched in ethanol, thus lowering the freezing point. Therefore, the fluid flowing through the tube is also continually increasing in alcohol content.

- The system design should be such that the flow area temperatures should remain above -14.3°C (6.2°F) until regeneration is complete.

A simplication of this process has been used as the criteria for the math model. Our aim has been to ensure that the expansion system remains warmer than the heat sink reservoir during the entire cool down period. The initial cases run with the thermal model indicated that this was not happening. To explain this, it is necessary to understand that the time for a part to cool is related to its thermal mass and its conductance to the driving temperature (the heat sink). The property of a part that defines the time for a part to change temperature is called the time constant which is defined as $mc_p/\Sigma G$; where mc_p is the thermal mass of the part, and ΣG is the sum of the conductances to adjacent parts. The larger the time constant, the longer it takes for a part to reach equilibrium. Because of the large latent energy associated with the heat sink, the effective thermal mass and its time constant are quite large compared to those areas which

do not contain solution. Cool down time for the sink was, therefore, much longer than the accumulator. Corrective action would not be directed toward the thermal mass - this is a constant in the analysis - but toward the conductance to the heat sink. Conductance to the heat sink had to be increased, thus reducing the time constant while flow section time constants were increased by reducing conduction to the environment. In actual practice, this will be achieved by insulating to slow cooling and by increasing convection (such as by fan-forced air) to increase cooling.

A 30 node thermal model was prepared to describe this cooling transient case. The model is described in Appendix B and includes 13 fluid nodes in addition to nodes on the insulation, tank metal, battery, and pump. Conductances were calculated between internal connecting nodes and for connections to the environment for those nodes on the outside of the package.

In programming the cooling model, several assumptions were made. The total heat released, due to heat of fusion and solution from the Fusible Heat Sink is 512 J/g (220 Btu/lb). It was assumed that this heat is released over the temperature range of -14.3°C (6.2°F) to -7.3°C (18.8°F). In order to facilitate this in the program, the fluid specific heat was defined as 220/(18.8-6.2), or 73.3 J/g-°C (7.5 Btu/lb-°F) for this temperature range. A value of 3.35 J/g-°C (0.8 Btu/lb-°F) was used for temperatures above -7.3°C (18.8°F).

Above a temperature of -7.3°C (18.8°F), the thermal conductivity of the solution was assumed to be 0.0065 W/cm-°C (0.375 Btu/hr-ft-°F). This was increased linearly with decreasing temperature to a value of 0.0225 W/cm-°C (1.3 But/hr-ft-°F) over the range from -7.3°C (18.8°F) to -14.3°C (6.2°F). The higher figure is the thermal conductivity of ice at 0°C (32°F).

The outer surface of insulation releases heat to the cold surroundings at -17.8°C (0°F) by radiation and convection. The emissivity used at the outer insulation surfaces was 0.05 (gold or aluminum foil). The view factor was taken as 1.0, as it was for all other radiation conductors. Radiation conductors from the tank surface have an emissivity of 1.0. Convective heat transfer was increased to the bare metal surfaces of the heat sink nodes and not to the insulation where the heat transfer rate was held to natural convection at $h = 5.67 \times 10^{-4}$ W/cm^2-°C (1.0 Btu/hr-ft^2-°F).

Metal parts of the package were assumed to be stainless steel having a thermal conductivity of 0.147 W/cm-°C (8.5 Btu/hr-ft-°F). An insulation conductivity of 3.5×10^{-4} W/cm-°C (0.02 Btu/hr-ft-°F) was also used. The insulation thickness was held to 1.27 cm (0.5 inches).

The motor was modeled with a plastic sleeve, mounted from the top of the cover to the lower portion of the magnetic coupling so that only the lower portion of the pump is in direct contact with fluid.

A heater less than 1 watt is required for the disconnect tube to prevent preliminary freeze. This was simulated in the model by putting the dissipated power directly into the metal tube.

Analytical results are shown in Figures 10 through 17 for the cool down model. Figure 10 shows a typical transient profile, while Figure 11 shows total energy removal versus cool down time. Figures 12, 13, and 14 show nodal temperatures after 10 hours of cooling, while Figures 15, 16, and 17 reflect 30 hours of cooling.

NORMAL MODE OPERATION

The warm-up model differs somewhat from the cool down model and is described in Appendix B. The expansion circulation tube is missing along with tube fluid and tube insulation. The warm-up model includes a fluid node in the pump, 16.4 cm^3 (1 in^3), and in the external loop, 81.9 cm^3 (5 in^3). Two additional insulation nodes are included so that the package is entirely covered with insulation. Heat is added to the fluid in the external loop to simulate the heat input from the LCG heat exchanger. Flow conductors connect the outside fluid loop to the fluid flowing within the Fusible Heat Sink package.

The flow rate is 108.9 kg/hr (240 lb/hr). The warm-up model was run for heat exchanger loads of 422, 1,583, and 2,100 kJ/hr (400, 1,500, and 2,000 Btu/hr). The pump motor power is 27 W (92.1 Btu/hr). This power was put into the pump/motor node. The fluid in the pump was connected to the pump with a suitable conductance value. Figure 18 shows the results of this analysis which indicates that pump outlet temperature is maintained below 0°C (32°F) for one hour with a heat exchanger load of 2,100 kJ/hr (2,000 Btu/hr) in the external fluid circulation loop.

SUMMARY

Two thermal models were prepared for use as a tool to describe the thermal effects of physical changes to the Fusible Heat Sink. The cool down model shows the temperature response of the package while the package is being refrigerated. The second, warm-up,

CURVES BASED ON: $h = 1.7 \times 10^{-3}$ W/cm^2-°C (3 Btu/hr-ft^2-°F) TO UNINSULATED SECTIONS

ENVIRONMENT TEMPERATURE = -17.8°C (0°F)

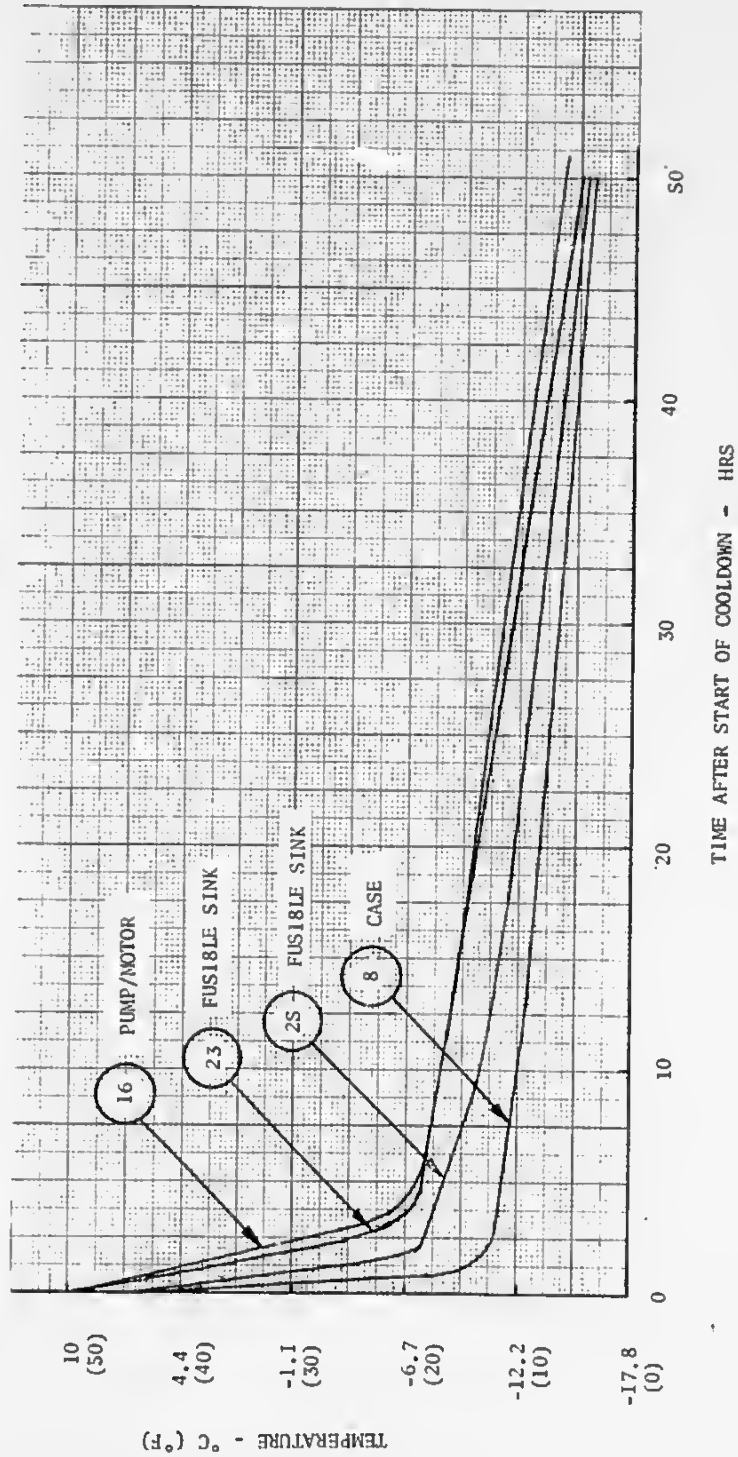

FIGURE 10: THERMAL RESPONSE OF FUSIBLE HEAT SINK DURING COOLDOWN

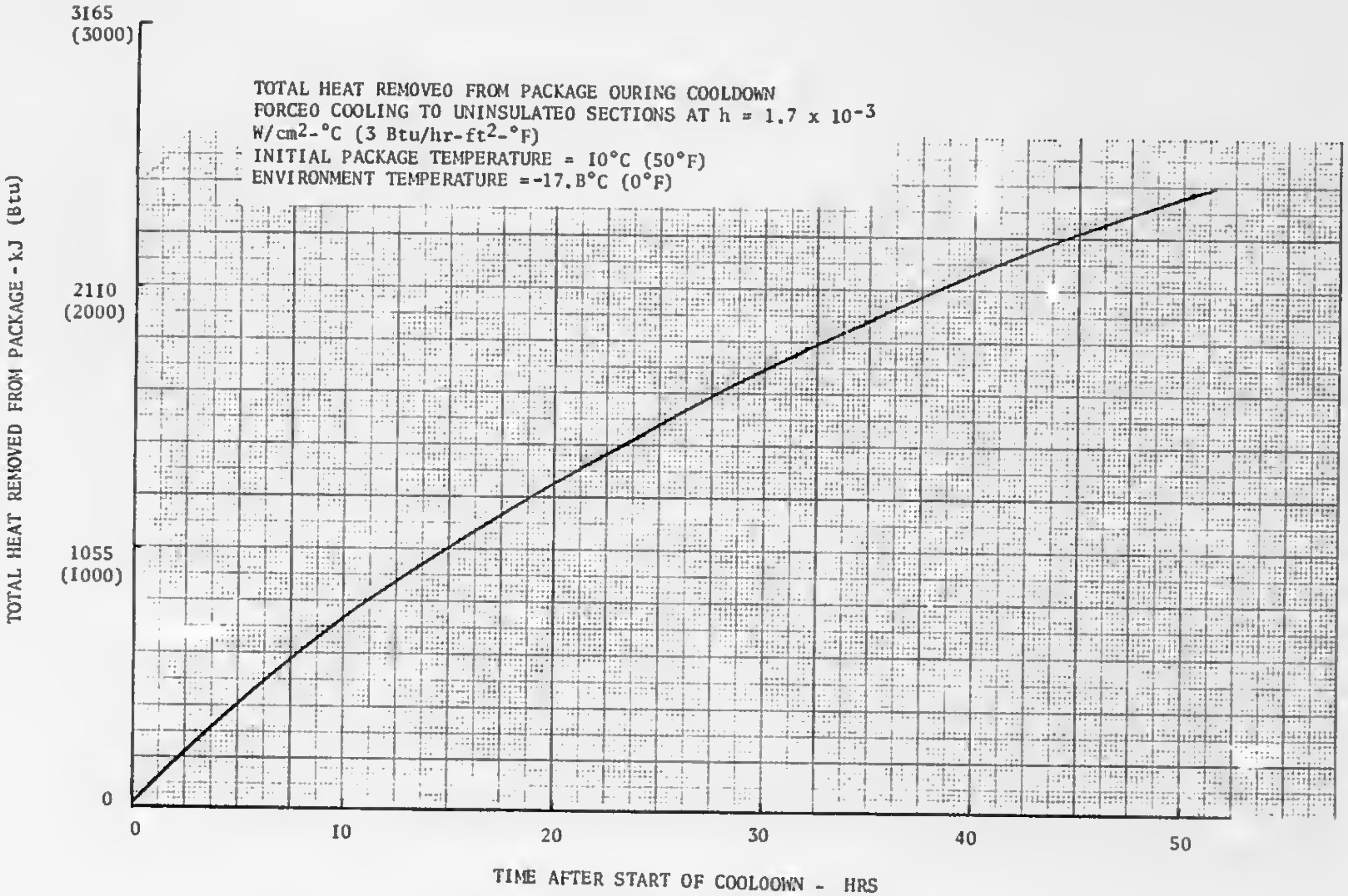

FIGURE 11: FUSIBLE HEAT SINK - COOLDOWN CONOITION

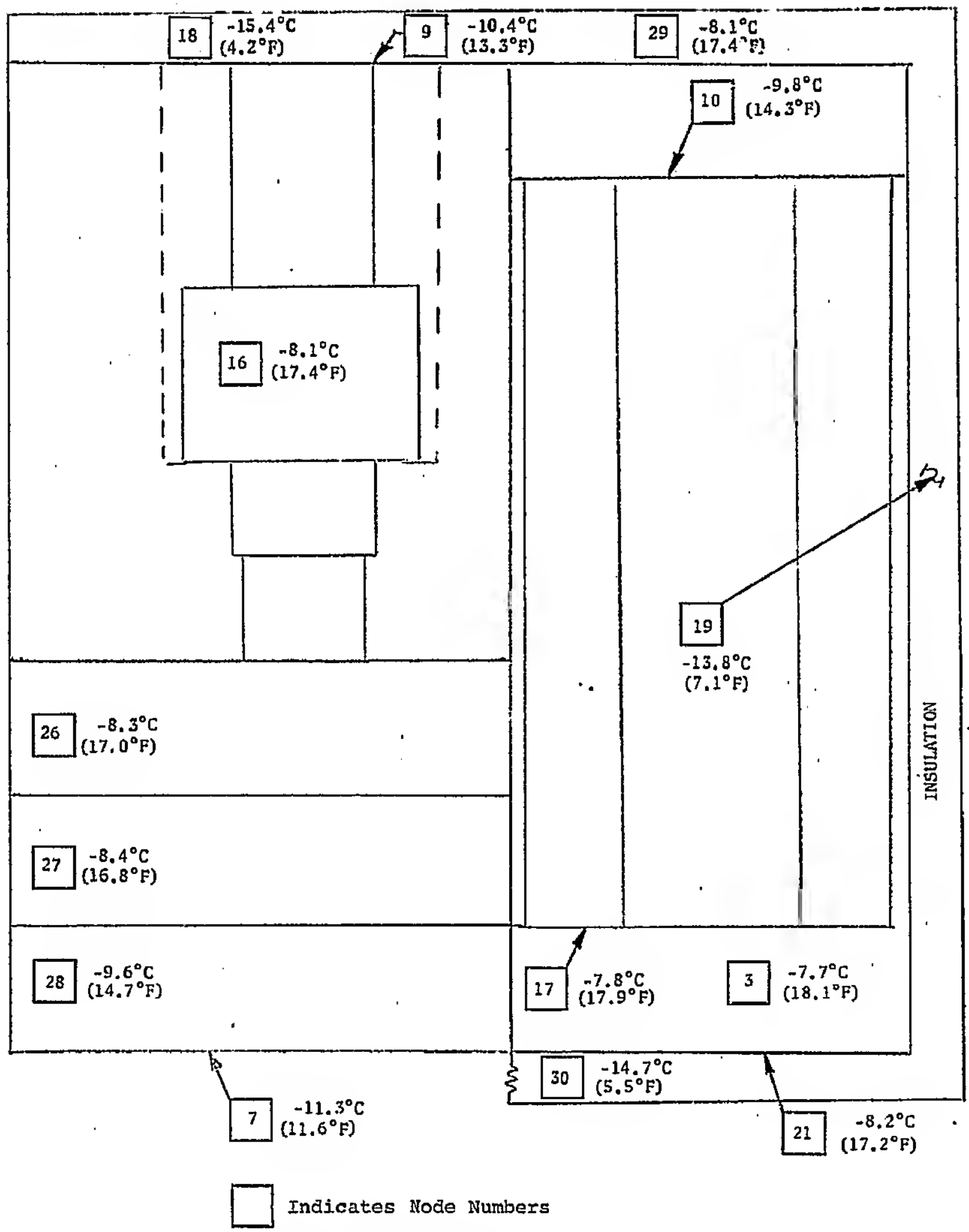

FIGURE 12: FUSIBLE HEAT SINK COOLDOWN

SIDE VIEW - TIME = 10 HOURS

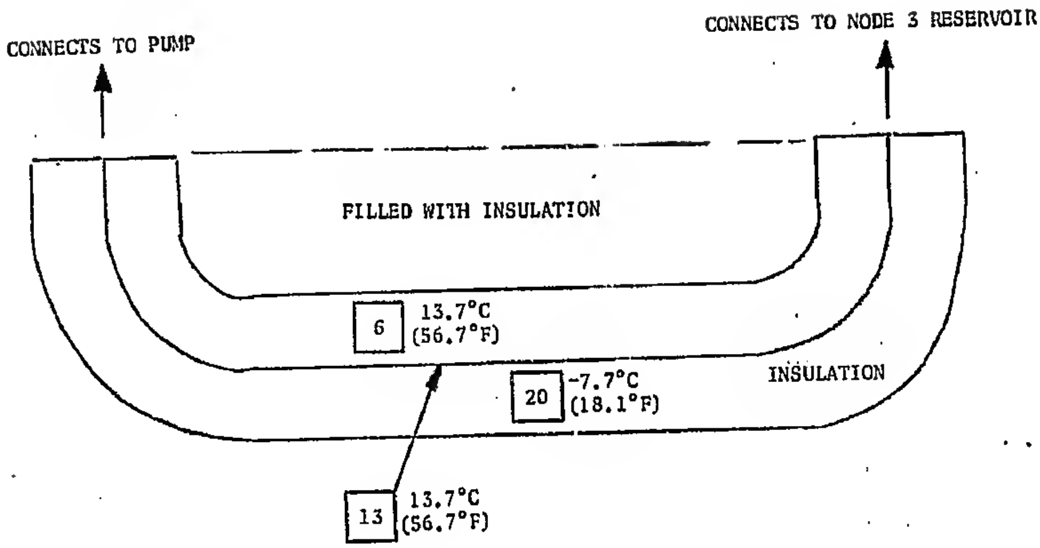

FIGURE 13: FUSIBLE HEAT SINK COOLDOWN
EXPANSION CIRCULATION TUBE - TIME = 10 HOURS

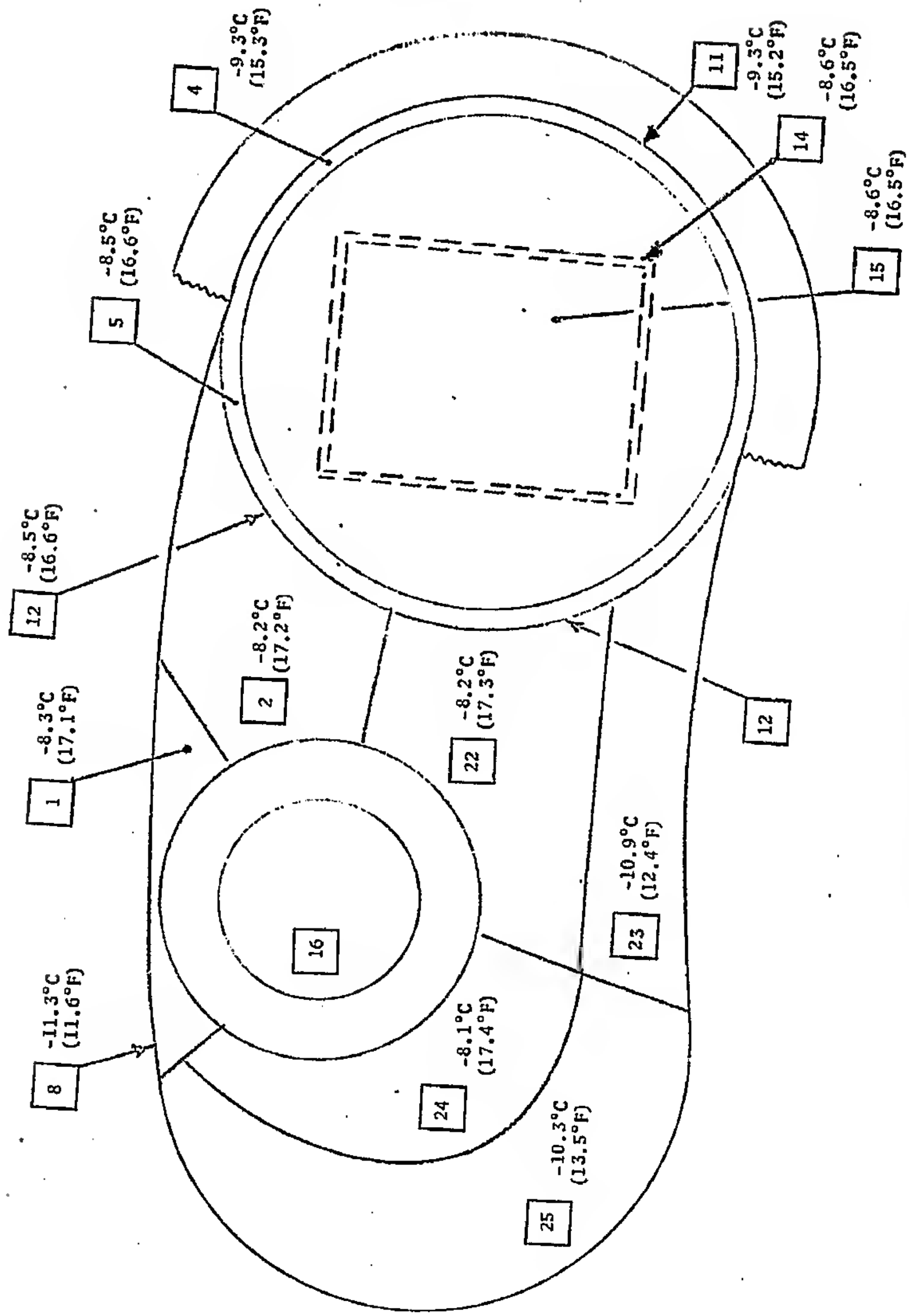

FIGURE 14: FUSIBLE HEAT SINK COOLDOWN

TOP VIEW - TIME = 10 HOURS

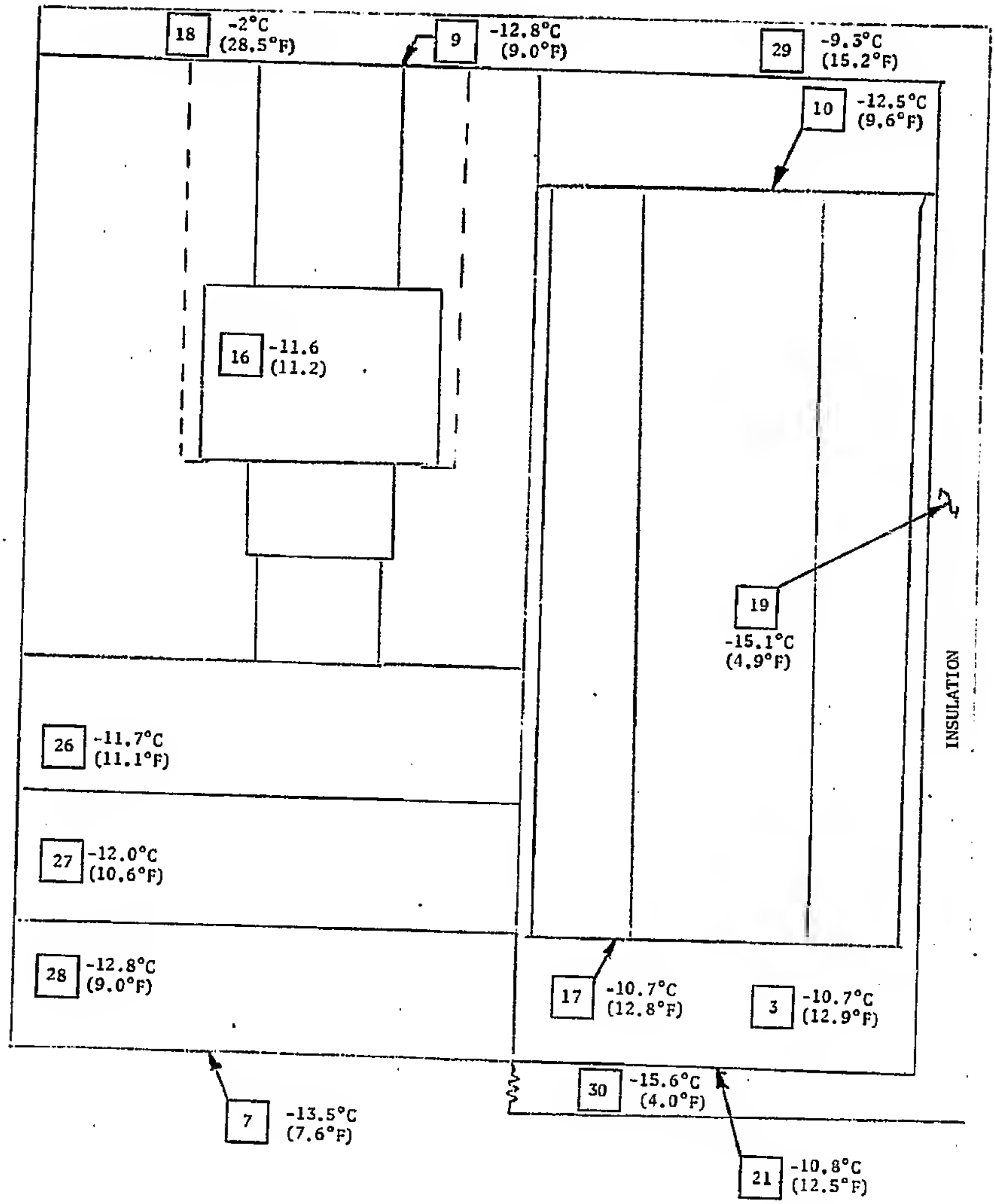

FIGURE 15: FUSIBLE HEAT SINK COOLDOWN
SIDE VIEW - TIME = 30 HOURS

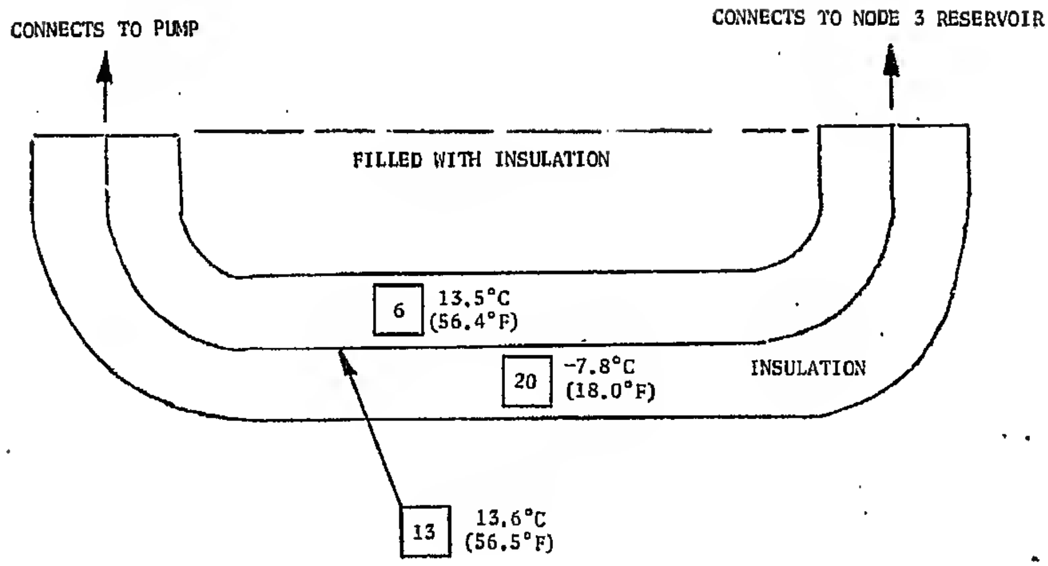

FIGURE 16: FUSIBLE HEAT SINK COOLDOWN
EXPANSION CIRCULATION TUBE - TIME = 30 HOURS

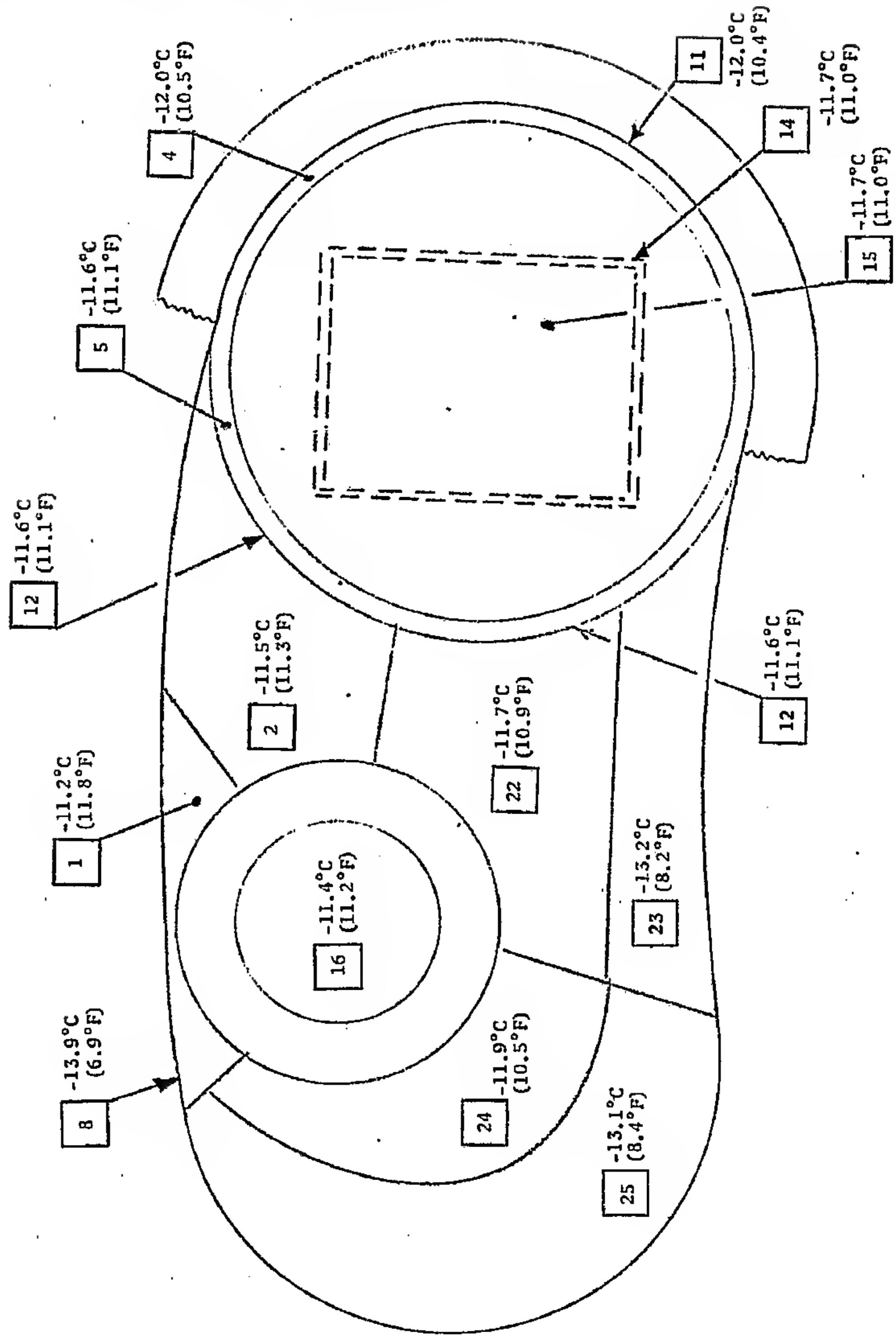

FIGURE 17: FUSIBLE HEAT SINK COOLDOWN
TOP VIEW - TIME = 30 HOURS

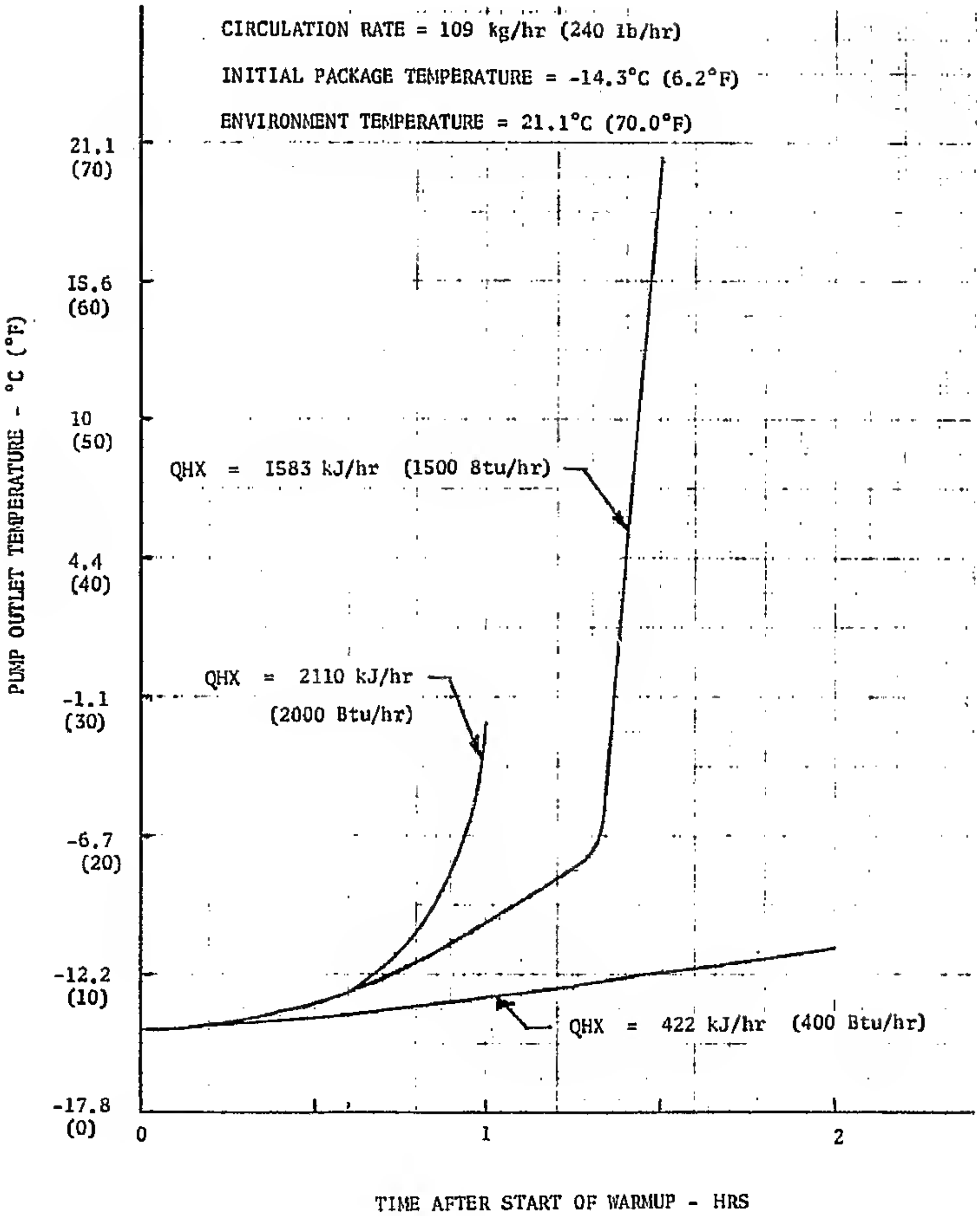

FIGURE 18: FUSIBLE HEAT SINK WARMUP CONDITION PUMP OUTLET TEMPERATURE VERSUS TIME

model shows the temperature response of the package while warmed fluid is being circulated to it from the LCG heat exchanger loop. The results of this study show that critical areas of the heat sink package must be thermally isolated from the -17.7°C (0°F) refrigerant to ensure free flow pumping at minimum package temperatures. Conversely, to attain reasonable cool down or recharge time, the thermal conductance between the refrigerant and heat sink must be maximized. The model has shown that the areas to be insulated include the entire battery section, the top of the motor section, and a section of the motor (reservoir) section where the pump is closest to the side wall. Additionally, the cool down time can be significantly decreased by adding internal fins to the slurry tank, and by supplying forced air circulation within the freezer or clamping the slurry tank directly to the freezer wall.

In the operational or warm-up mode, the pump discharge fluid temperature remains below 0°C (32°F) while providing a total available heat sink of 2,110 kJ (2,000 Btu).

COMPONENT AND SYSTEM SPECIFICATIONS

SYSTEM SPECIFICATION

Performance - A detailed system performance specification is included in the Preliminary Design section of this report.

Operating Temperature - -17.8°C (0°F) to 21.1°C (70°F)

Envelope - The system exclusive of the suit mounted heat exchanger shall not exceed the following envelope: 30.5 cm (12 in) high x 26.7 cm (10.5 in) wide x 14.0 cm (5.5 in) deep. The heat exchanger shall not exceed the following envelope: 17.8 cm (7.0 in) long x 16.0 cm (6.3 in) wide x 3.6 cm (1.4 in) deep, including headers.

Weight - The system exclusive of the suit mounted heat exchanger shall not exceed the following weight: 10.52 kg (23.19 lb) wet, 6.35 kg (13.99 lb) dry. The heat exchanger shall not exceed the following weight: 1.56 kg (3.45 lb) wet, 0.70 kg (1.56 lb) dry.

Vehicle Interfaces - A freezer with internal dimensions no less than 30.5 cm x 26.7 cm x 14.0 cm (12 in x 10.5 in x 5.5 in), and an internal temperature of -17.8°C (0°F) is required for refreeze of the slurry. Additionally, two 27 VDC electrical connectors are required for battery recharge at 0.1 ampere maximum and for expansion tube heating at 0.037 ampere.

Suit Interface - The LCG heat exchanger mounts on a suitable portion of the suit where it penetrates the pressure shell and mates with the inlet and outlet lines from the LCG. No other suit interfaces are required.

External Leakage - There shall be no measurable external leakage when the system is pressurized with water to a pressure of 69 kPa delta (10 psid).

COMPONENT SPECIFICATIONS

Detail specifications for the components that make up the system are presented in this section. Figure 7 shows a detail cross section of all components, except the heat exchanger which is shown in Figure 19.

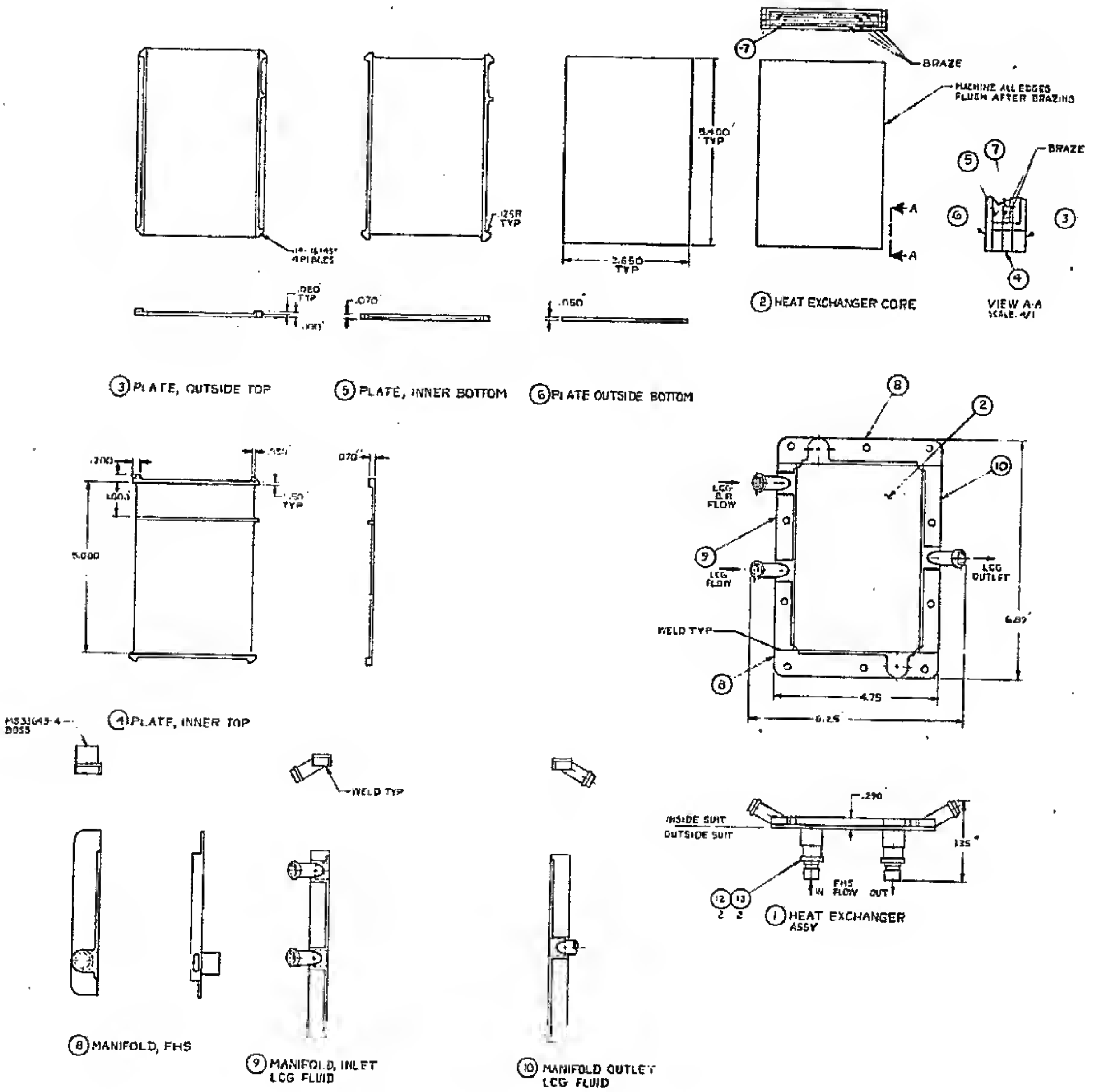

FIGURE 1?: LIQUID COOLING GARMENT HEAT EXCHANGER CONCEPT

HAMILTON STANDARD Division of UNITED TECHNOLOGIES

Slurry Tank Specification

Performance - The slurry tank shall be constructed to contain 3,700 cm^3 (230 in^3) of potassium bifluoride-water-ethanol solution. In addition, the tank shall have sufficient volume to contain internally the following items:

- Pump/Motor
- Battery
- Accumulator
- Inlet and Outlet Disconnect
- Check Valve

The tank shall contain mounting provisions for these components and shall provide a separate chamber for the accumulator to which the inlet disconnect and check valve can be attached. The tank shall be covered with molded rigid closed cell insulating foam in the areas shown on Figure 19, with aluminum foil tape covering exposed foam surfaces.

The tank shall be capable of withstanding a proof pressure of 258 kPa (37.5 psig) and a burst pressure of 345 kPa (50 psig).

Operating Temperature - -17.8°C (0°F) to 21.1°C (70°F)

Envelope - The tank shall not exceed the following envelope: 30.5 cm x 25.4 cm x 12.7 cm (12 in x 10 in x 5 in).

Weight - The tank shall not weigh more than 2.37 kg (5.22 lb).

Interfaces - The tank shall utilize the two female disconnects as two of three mounting points and shall provide a means of actuating those disconnects from an accessible position by a suited astronaut. The third mounting point shall be a ball lock pin equally accessible. Actuation of the disconnects shall not be possible until the ball lock pin has been removed.

Construction - The tank shall be constructed of welded stainless steel.

External Leakage - There shall be no measurable external leakage utilizing water at a pressure differential of 69 kPa (10 psi).

Internal Leakage - Leakage between the tank interior and the accumulator chamber shall not exceed 1.25 x 10^{-5} g/s (10^{-4} lb/hr) of water with the tank pressurized 69 kPa (10 psi) greater than the chamber.

Accumulator Specification

Performance - The accumulator shall be a rubber bladder enclosed air volume capable of absorbing 327.7 cm3 (20 in^3) of slurry tank volume expansion without exceeding 69 kPa (10 psi) pressure increase. The bladder shall contain dry air at -20°C (-4°F) dew point, 21.1°C (70°F) dry bulk at 101 kPa absolute (14.7 psia) in the uncompressed state.

Operating Temperature - -17.8°C (0°F) to 21.1°C (70°F)

Envelope - The accumulator envelope shall not exceed 10.16 cm (4 in) diameter x 20.3 cm (8 in) length. Note: Battery may be partially contained within this volume.

Weight - The accumulator shall not weigh more than 0.10 kg (0.22 lb).

Interfaces - The accumulator shall be constructed as an integral part of the battery case. An "O" ring sealed port shall be provided to allow repressurization of the air in the accumulator bladder.

Construction - The accumulator bladder shall be silicon rubber. Stainless steel clamps and a suitable adhesive shall attach the bladder to the battery interface.

External Leakage - There shall be no measurable external leakage utilizing water at a pressure differential of 69 kPa (10 psi).

Internal Leakage - Leakage between the accumulator chamber and the tank interior shall not exceed 1.25 x 10^{-5} g/s (10^{-4} lb/hr) of water with the chamber pressurized 69 kPa (10 psi) greater than the tank.

Battery Specification

Performance - The battery shall provide 36 watt hours of energy for a D.C. motor at 27 VDC and 1 ampere maximum current draw. The battery shall contain a hermetically sealed switch and an electrical connector as shown on Figure 19. The battery case shall provide a relief valve to prevent case pressure from exceeding 172 kPa (25 psig). The battery shall provide mounting provisions for the accumulator and shall be partially contained therein.

Operating Temperature - -17.8°C (0°F) to 21.1°C (70°F)

Envelope - The battery with accumulator attached shall not exceed 10.16 cm (4 in) diameter x 25.4 cm (10 in) length.

Weight - The battery with accumulator attached shall not exceed 1.83 kg (4.03 lb).

Interfaces - The battery shall provide a single electrical connector for interface with the unit pump/motor and for battery recharge. The battery switch shall be located where it is accessible to a suited astronaut. The battery shall be mounted to the slurry tank and provide an external seal to the accumulator chamber.

Construction - The battery shall be of welded stainless steel construction.

External Leakage - There shall be no measurable external leakage utilizing water at a pressure differential of 69 kPa (10 psi).

Pump/Motor Specification

Performance - The pump/motor combination shall consist of a brush type D.C. motor magnetically coupled to a gear type pump supported in such a way as to expose the motor and coupling to ambient air while the pump is immersed in the slurry tank fluid. The pump shall flow 30.2 g/s (4 lb/min) of slurry tank fluid against a pressure head of 27.5 kPa (4 psi) maximum. The maximum motor power shall be 27 watts at 27 VDC.

Operating Temperature - -17.8°C (0°F) to 21.1°C (70°F)

Envelope - The pump/motor and supports shall not exceed 11.43 cm (4.5 in) diameter x 16.51 cm (6.5 in) length.

Weight - The pump/motor assembly shall not exceed 1.17 kg (2.58 lb).

Interfaces - The pump/motor support shall interface with and seal the top of the slurry tank at the outlet disconnect location. The pump/motor assembly shall provide a type MS33649-4 boss for attachment of the outlet disconnect. The pump/motor assembly shall provide a 7.9 x 7.9 per cm (20 x 20 per in) mesh screen at the pump inlet. The pump/motor assembly shall provide an electrical connector with a 12.7 cm (5 in) lead for connection with the battery.

Construction - The motor and coupling shall be of unrestricted construction. The pump shall be of stainless steel and teflon construction. The pump and motor supports shall be Kel-F-81 plastic.

External Leakage - The external leakage of the pump shall not exceed 1.25 x 10^{-4} g/s (10^{-3} lb/hr) water at 27.5 kPa (4 psig).

Internal Leakage - The nonoperating reverse flow internal leakage of the pump shall not be less than 0.063 g/s (0.05 lb/hr) water with a 6.9 kPa (1 psi) pressure differential.

Disconnect Specification

Performance - The disconnect shall be of the zero-spill configuration and shall have a maximum water spillage or air inclusion of 16.39 x 10^{-5} cm^3 (1 x 10^{-5} in^3) per cycle. The connection force shall not exceed 4.54 kg (10 lb). The pressure drop shall not exceed 3.45 kPa (0.5 psi) with a slurry tank fluid flow of 30.2 g/s (4 lb/min). The external leakage from either half of the disconnect when engaged or disengaged shall not exceed 0.000125 g/s (0.001 lb/hr) water at 103 kPa at 15 psig pressure.

Operating Temperature - -17.8°C (0°F) to 21.1°C (70°F)

Envelope - The envelope of the female half of the disconnect shall not exceed 3.05 cm (1.2 in) diameter x 6.35 cm (2.5 in) long, and the envelope of the male half shall not exceed 2.54 cm (1 in) diameter x 5.08 cm (2.0 in) long.

Weight - The weight of the disconnect halves shall not exceed 0.02 kg (0.045 lb) for one male half and 0.85 kg (0.19 lb) for one female half.

Interfaces - The disconnects shall have a type MS33656E4 port on one end and shall be compatible with the mating half at the other end.

Construction - The disconnects shall be of stainless steel construction with elastomer seals.

External Leakage - There shall be no measurable external leakage utilizing water at a pressure differential of 69 kPa (10 psi).

Check Valve Specification

Performance - The check valve shall flow 30.2 g/s (4 lb/min) of slurry tank fluid in the flow direction without exceeding 3.45 kPa (0.5 psi) pressure drop. Reverse flow leakage shall not exceed 0.0000125 g/s (0.0001 lb/hr) at 0.138 kPa (0.02 psi) pressure differential.

External Leakage - There shall be no measurable external leakage utilizing water at a differential of 69 kPa (10 psi).

Insulation Blanket Specification

Performance - The insulation blanket shall completely enclose the assembled slurry tank and in conjunction with the rigid insulation on the tank shall limit the heat transfer from the tank at a temperature differential of 36°C (65°F) in a one 'g' environment to a maximum of 14.66 J/s (50 Btu/hr). The blanket shall be configured as shown on Figure 19 and shall be removable for freeze up mode operation. Access by a suited astronaut shall be provided to the battery switch and recharge connector during operation.

Operating Temperature - -17.8°C (0°F) to 21.1°C (70°F)

Envelope - The insulation blanket shall conform to the exterior of the slurry tank and shall not exceed 1.27 cm (0.5 in) thickness.

Weight - The weight of the insulation blanket shall not exceed 0.24 kg (0.52 lb).

Interfaces - The insulation blanket shall interface with the slurry tank.

Construction - The insulation blanket for the flight prototype unit shall be constructed of 20 layers aluminized mylar with fiber glass Beta cloth separators and cover. Velcro hook and pile, and snaps shall be used to provide removability and access. In the areas where fixed insulation is attached to the slurry tank, only cover material, no mylar and separators, shall be used. The feasibility and functional system hardware will incorporate an insulation blanket that duplicates the thermal performance of the flight prototype blanket but is constructed of less exotic and costly materials.

Heat Exchanger Specification

Performance - The heat exchanger shall be sized to transfer a maximum of 586.6 J/s (2,000 Btu/hr) from slurry tank fluid flowing at 30.2 g/s (4 lb/min) and -7.3°C (18.8°F) to the LCG water loop flowing at 30.2 g/s (4 lbs/min) and 14.6°C (58.3°F). The heat exchanger shall be of a configuration that allows operation after partial freezing of the LCG water flow passes due to low heat load operation of 117.3 J/s (400 Btu/hr) with the slurry tank fluid at -14.3°C (6.2°F) and 30.2 g/s (4 lb/min) and the LCG water flow at 22°C (71.2°F) and 30.2 g/s (4 lb/min). The

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heat exchanger shall contain two male disconnect halves to interface with the slurry tank. The pressure drop through either loop shall not exceed 6.89 kPa (1 psi) at 30.2 g/s (4 lb/min) flow. The heat exchanger shall be capable of withstanding a proof pressure of 258 kPa (37.5 psig) and a proof pressure of 345 kPa (50 psig).

Operating Temperature - -17.8°C (0°F) to 21.1°C (70°F)

Envelope - The heat exchanger shall not exceed an envelope of 17.8 cm x 12.2 cm x 0.76 cm (7.0 in x 4.8 in x 0.3 in) exclusive of inlet/outlet bosses and 17.8 cm x 16.0 cm x 3.6 cm (7.0 in x 6.3 in x 1.4 in) with bosses and disconnects included.

Weight - The heat exchanger weight shall not exceed 1.56 kg (3.45 lb) wet or 0.70 kg (1.56 lb) dry.

Interfaces - The heat exchanger shall have 0.952 cm (0.375 in) beaded tube ends for interface with the LCG loop, and male half disconnects for interface with the slurry tank. The heat exchanger shall have provisions for interfacing with the pressure bladder wall of the space suit with the LCG interfaces inside the suit and the disconnect interfaces outside the suit.

Construction - The heat exchanger shall be of stainless steel plate fin construction with a brazed core and headers attached by welding.

External Leakage - There shall be no measurable external leakage utilizing water at a pressure differential of 69 kPa (10 psi) in any direction.

Internal Leakage - There shall be no internal leakage between the LCG loop and the slurry loop utilizing water at a pressure differential of 69 kPa (10 psi) in any direction.

APPENDIX A

SUPPORTING HEAT EXCHANGER CALCULATIONS

Heat Exchanger Sizing

High load, end of mission (Case VI)

$$LMTD = \frac{(50-18.8) - (58.3-28.5)}{\ln \frac{(50-18.8)}{(58.3-28.5)}} = 30.5°F$$

$$UA_{req'd} = \frac{Q}{LMTD} = \frac{2000 \text{ Btu/hr}}{30.5°F}$$

$$= 66 \frac{\text{Btu}}{\text{hr-}°\text{F}}$$

Low load, start of mission (Case I)

$$LMTD = \frac{(71.7-8.1) - (32-6.2)}{\ln \frac{(71.7-8.1)}{(32-6.2)}} = 42.5°F$$

$$UA_{req'd} = \frac{400}{42.5} = 9.4 \frac{\text{Btu}}{\text{hr-}°\text{F}}$$

Can ice thickness provide this reduction in heat exchanger conductance?

$$\frac{1}{UA_{req'd_{low}}} = \frac{1}{UA_{req'd_{high}}} + \text{Ice Resistance}$$

$$\frac{1}{9.4} = \frac{1}{66} + \frac{\Delta X}{KA}$$

$$\Delta X = [.106 - .015](1.3)A$$

$$= .118A$$

Assume $A \cong .5 ft^2$

$$\Delta X = (.118)(.5)(12 \frac{in}{ft})$$

$$= .7 \text{ inch}$$

Too thick for practical application!

Tube in Tube Heat Exchanger

Inner tube: O.D. = 0.125"
I.D. = 0.099"

Outer tube: I.D. = 0.333"

Water flow in annulus:

$$D_e = \frac{\frac{\pi}{4}(.333^2 - .125^2)4}{\pi(.333 + .125)(12)} = 0.017 \text{ ft}$$

$$G = \frac{w}{A}$$

$$= \frac{240 \text{ lbs/hr}}{\frac{\pi}{4}(.333^2 - .125^2)} \times 144 \frac{in^2}{ft^2}$$

$$= 461{,}908 \frac{lb}{hr\text{-}ft^2}$$

$$N_{Re} = \frac{D_e G}{\mu}$$

$$= \frac{(.017)(461{,}908)}{(3.1)} = 2533$$

$$\frac{hD_e}{K} = .023\,(N_{Re})^{.8}\left(\frac{C_P\mu}{K}\right)^{.4}$$

$$h_{An} = \frac{(.023)(.332)}{(.017)}(2533)^{.8}\left(\frac{(1.0)(3.1)}{.332}\right)^{.4}$$

$$= 580 \frac{Btu}{hr\text{-}ft^2\text{-}^\circ F}$$

Slurry flow in tube:

$$De = \frac{.099}{12} = .00825 \text{ ft}$$

$$G = \frac{W}{A}$$

$$= \frac{240}{\frac{\pi}{4}(.099)^2} \times 144 = 4489660 \quad \frac{\text{lb}}{\text{hr-ft}^2}$$

$$N_{Re} = \frac{DeG}{\mu}$$

$$= \frac{(.00825)(4489660)}{(12.1)} = 3061$$

$$\frac{hDe}{K} = .023\,(N_{Re})^{.8}\left(\frac{CP\mu}{K}\right)^{.4}$$

$$h_{tube} = \frac{.023(.26)}{.00825}\,(3061)^{.8}\left(\frac{(.785)(12.1)}{(.26)}\right)^{.4}$$

$$= 1879.4 \quad \frac{\text{Btu}}{\text{hr-ft}^2\text{-}^\circ\text{F}}$$

$$\frac{1}{UA_{req'd}} = \frac{1}{h_{An}A_{An}} + \frac{1}{h_{tube}A_{tube}}$$

$$\frac{1}{66} = \frac{1}{(580)\,\frac{\pi(.125)\,L}{12}} + \frac{1}{1879.4\,\frac{\pi(.099)L}{12}}$$

$$.0152 = \frac{.0527}{L} + \frac{.02053}{L}$$

$$L = 4.82 \text{ ft}$$

Calculate water pressure drop:

$$V = \frac{G}{\rho}$$

$$= \frac{461,908}{(62.4)\ (3600\ \text{sec/hr})}$$

$$= 2.06\ \frac{\text{ft}}{\text{sec}}$$

$$f = .006 \quad \text{(smooth tube)}$$

$$\Delta P = 4f\ \frac{L}{D}\ \frac{\rho V^2}{2g_c}$$

$$= (4)(.006)\ \frac{(4.82)}{(.017)}\ \frac{(62.4)(2.06)^2}{2(32.17)(144)}$$

$$= .19\ \text{psi}$$

Shell and Tube Heat Exchanger

Use 150 1/8" tubes by 1.75" long, .082 Crimp. One pass shell side, one pass tube side.

Water (tube) side:

$$\text{Flow Area} = N_T\ \frac{\pi\ di^2}{4}$$

$$= (150)\pi\ \frac{(.099)^2}{4(144)}$$

$$= .008\ \text{ft}^2$$

$$G = \frac{W}{A} = \frac{240\ \text{lb/hr}}{.008\ \text{ft}^2}$$

$$= 30000\ \frac{\text{lb}}{\text{hr-ft}^2}$$

$$De = \frac{.099}{12} = .00825\ \text{ft}$$

$$N_{Re} = \frac{DeG}{\mu}$$

$$= \frac{(.00825)(30000)}{3.1} = 79.8$$

$$j = N_{Nu} \; N_{Pr}^{-.4} = 1.9 \quad \text{(Test Data .082 Crimp)}$$

$$\frac{hD}{K} = 1.9 \left(\frac{CP\mu}{K}\right)^{.4}$$

$$h_t = 1.9 \, \frac{K}{D} \left(\frac{CP\mu}{K}\right)^{.4}$$

$$= \frac{1.9(.332)}{(.00683)} \left(\frac{(1.0)(3.1)}{(.332)}\right)^{.4}$$

$$= 225.7 \text{ Btu/hr-ft}^2\text{-°F}$$

Slurry (shell) side:

$$\text{Flow Area} = .5 \, \frac{\text{in}^2}{\text{in length}} \times 1.75 \text{ in} \quad \text{(Design Data)}$$

$$= .875 \text{ in}^2$$

$$= 6.076 \times 10^{-3} \text{ ft}^2$$

$$G = \frac{W}{A} = \frac{240}{6.076 \times 10^{-3}} = 39497 \; \frac{\text{lb}}{\text{hr-ft}^2}$$

$$De = \frac{.125}{12} = .01042 \text{ ft}$$

$$N_{Re} = \frac{DeG}{\mu}$$

$$= \frac{(.01042)(39497)}{12.1} = 34$$

$$N_{Nu} N_{Pr}^{-.33} = 2.5 \quad \text{(Test Data)}$$

$$h_s = \frac{K}{D} \left(\frac{CP\mu}{K}\right)^{.33} (2.5)$$

$$= \frac{(.26)}{(.01042)} \left(\frac{(.785)(12.1)}{(.26)}\right)^{.33} (2.5)$$

$$= 204.5 \ \frac{Btu}{hr\text{-}ft^2\text{-}°F}$$

$$\frac{1}{UA} = \frac{1}{h_t A_t} + \frac{1}{h_s A_s}$$

$$\frac{1}{UA} = \frac{1}{(225.7) \ \frac{\pi(.099)(1.75)(150)}{144}} + \frac{1}{(204.5) \ \frac{\pi(.125)(1.75)(150)}{144}}$$

$$UA = 68.3 \ \frac{Btu}{hr\text{-}°F}$$

Calculate water pressure drop:

$$G = \frac{240(144)(4)}{(150)(\pi)(.082)^2} = 43628 \ \frac{lb}{hr\text{-}ft^2}$$

$$N_{Re} = \frac{GDe}{\mu}$$

$$= \frac{43628(.082)}{12(12.1)}$$

$$= 24.6$$

$$V = \frac{G}{\rho} = \frac{43628}{62.4} = 699 \ \frac{ft}{hr}$$

$$V = 699/3600 = .194 \ \text{FPS}$$

$$4f = \frac{64}{24.6} = 2.6 \qquad \text{(Laminar flow)}$$

$$\Delta P = 4f \frac{L}{D} \frac{\rho V^2}{2g_c}$$

$$= (2.6)\frac{(1.75)}{(.082)} \frac{(62.4)(.194)^2}{(2)(32.17)(144)}$$

$$= .014 \text{ psi}$$

Plate Fin Heat Exchanger

Assume minimum Nusselt number:

$$N_{Nu} = 4.5 \qquad \text{(Test Data)}$$

Water fin is 0.050" high, ruffled, 35 fpi, .002 thick

$$De = .00258 \text{ ft}$$

$$h_w = 4.5 \frac{K}{De}$$

$$= 4.5 \frac{(.332)}{(.00258)} = 579 \frac{\text{Btu}}{\text{hr-ft}^2\text{-}^\circ\text{F}}$$

$$\frac{A_{HT}}{V} = 850 \frac{\text{ft}^2}{\text{ft}^3} \qquad \text{(650 secondary plus 200 primary)}$$

$$A_{HT} = (850)\ LxWxH$$

$$= \frac{(850)(3)(4)(.05)}{1728} = .295 \text{ ft}^2$$

Fin Effectiveness = .53

$$A_{HT} = \left[\frac{(.53)(650) + 200}{850}\right] .295$$

$$= .189 \text{ ft}^2$$

$$hA_{water} = (579)(.189) = 109 \frac{Btu}{hr-°F}$$

Slurry fin is .050" high, ruffled, 35 fpi, .002" thick

$$h_s = 4.5 \frac{K}{De}$$

$$= \frac{(4.5)(.26)}{.00258} = 453 \frac{Btu}{hr-ft^2-°F}$$

$$\frac{A_{HT}}{V} = 850 \frac{ft^2}{ft^3}$$ (650 secondary plus 200 primary)

$$A_{HT} = 850\ LxWxH$$

$$= \frac{(850)(3)(4)(2 \times .05)}{1728} = .59\ ft^2$$

Fin effectiveness = .4

$$A_{HT} = \left[\frac{(.4)(650) + 200}{850}\right].59 = .32\ ft^2$$

$$hA_{slurry} = (453)(.32)$$

$$= 145 \frac{Btu}{hr-°F}$$

$$\frac{1}{UA} = \frac{1}{hA_{water}} + \frac{1}{hA_{slurry}}$$

$$= \frac{1}{109} + \frac{1}{145}$$

$$UA = 62 \frac{Btu}{hr-°F}$$

Increase core length by .25" to 3.25".

$$UA = 62\left(\frac{3.25}{3}\right) = 67 \quad \frac{\text{Btu}}{\text{hr-}^\circ\text{F}}$$

Calculate water pressure drop:

$$A_{ff} = w \times h \times \text{Blockage factor}$$

$$= 4 \times .05 \times .56$$

$$= .112 \text{ in}^2$$

$$G = \frac{W}{A} = \frac{240}{.112}(144) = 308{,}571 \quad \frac{\text{lb}}{\text{hr-ft}^2}$$

$$V = \frac{G}{\rho} = \frac{(308{,}571)}{(62.4)(3600)} = 1.374 \quad \frac{\text{ft}}{\text{sec.}}$$

$$N_{Re} = \frac{GD}{\mu}$$

$$= \frac{(308{,}571)(.00258)}{(3.1)} = 257$$

$$f = \frac{16}{N_{Re}} = \frac{16}{257} = .0622$$

$$\Delta P = 4f\frac{L}{D}\frac{\rho V^2}{2gc}$$

$$= \frac{4(.0622)(3.25)}{(.00258)(12)}\frac{(62.4)(1.374)^2}{2(32.17)(144)}$$

$$= .332 \text{ psi}$$

APPENDIX B

FUSIBLE HEAT SINK THERMAL MODEL

APPENDIX B

CINDA Program Capabilities

In order to solve the transient solution the computer program CINDA was used. CINDA is a versatile analytical program written by Chrysler under a NASA contract. The data is input into the program in "blocks" where each block contains different kinds of information. These blocks are (1) Title, (2) Node data, (3) Conductor data, (4) Constants data, (5) Array data, (6) Execution, (7) Variables 1, (8) Variables 2, and (9) Output calls.

The Title block allows the user to input title cards into the program. In the Node data block the user places all of the numbered nodes into the program including their initial temperature and capacitance (C(N)) or thermal mass value. Boundary nodes are also placed in the Node data block. In the Conductance data block the conductor number, G(N), connecting nodes and the conductance value is input. A positive conductor number indicates a non-radiation conductor. A negative conductor number indicates a radiation conductor. In the Constants data block the user inputs constants as required by the various subroutines which the user may call. The Array data block contains arrays of data used by the subroutines that the user calls for in the different blocks. For example, thermal mass or conductance may be varied with temperature. Label arrays are also kept there, which are later called upon from the output calls block to label print-out data. In the Execution block the user identifies the size of the program and calls for the required internal subroutines from the CINDA library in order to solve the problem. In the Variables 1 block the user can perform pre-solution operations. For example, for a single power dissipation, the user may call STFSEP(61.5,Q27). This means that he is assigning 61.5 watts or Btu's to node 27. The Variables 2 section allows the user to perform post-solution calculations. That is, the user can extract information from the just-solved network. For example, the call QMETER(T1,T2,G1,K1) calculates the heat flow between nodes 1 and 2 as a function of conductance number 1 and places this calculated value into K1. As many QMETER calls as desired may be used. Then with an ADD(K1,K2,K3,K4) statement, for example, the user sums K1, K2 and K3 and places the sum into K4. In the Output calls block the user may call for a printout of the problem solution. CINDA has the additional flexibility that allows the user to include his own FORTRAN statements anywhere in the last 4 operation blocks.

The fusible heat sink cooldown model is described in Figures 1-B, 2-B, and 3-B, plus Table I-B. The warmup model is described by Figures 4-B and Table II-B. Enclosures are included for sample printout for both models.

TABLE I-B

NODE DESCRIPTION - COOLDOWN MODEL

Node Number	Description
1	Liquid Around Pump
2	Liquid Around Pump
3	Liquid Below Battery
4	Liquid Around Bladder (outer)
5	Liquid Around Bladder (inner)
6	Liquid in Expansion Tube
7	Metal S/S Bottom Below Motor
8	Metal S/S Side of Motor Section
9	Metal S/S Top of Motor Section
10	Metal S/S Top of Battery Section
11	Metal S/S Outer Side of Battery Section
12	Metal S/S Inner Side of Battery Section
13	Metal S/S Tube
14	Metal S/S Around Battery
15	Battery
16	Pump/Motor
17	Metal S/S Bottom of Battery
18	Insulation Atop Motor Section
19	Insulation Around Side of Battery Section
20	Insulation Around Tube
21	Metal S/S Bottom of Battery Section
22	Liquid Around Pump
23	Liquid Around Pump
24	Liquid Around Pump
25	Liquid Around Pump
26	Liquid Below Pump
27	Liquid Below Pump
28	Liquid Below Pump
29	Insulation Atop Battery Section
30	Insulation on Bottom of Battery Section
100	Environment

TABLE II-B

NODE DESCRIPTION - WARMUP MODEL

Node Number	Description
1	Liquid Around Pump
2	Liquid Around Pump
3	Liquid Below Battery
4	Liquid Around Bladder Outer
5	Liquid Around Bladder Inner
6	Insulation Around Side of Motor Section
7	Metal S/S Bottom Below Motor
8	Metal S/S Side of Motor Section
9	Metal S/S Top of Motor Section
10	Metal S/S Top of Battery Section
11	Metal S/S Outer Side of Battery Section
12	Metal S/S Inner Side of Battery Section
13	Insulation at Bottom of Motor Section
14	Metal S/S Around Batter
15	Battery
16	Pump/Motor
17	Metal S/S Bottom of Battery
18	Insulation Atop Motor Section
19	Insulation Around Side of Battery Section
20	Fluid in the Pump
21	Metal S/S Bottom of Battery Section
22	Liquid Around Pump
23	Liquid Around Pump
24	Liquid Around Pump
25	Liquid Around Pump
26	Liquid Below Pump
27	Liquid Below Pump
28	Liquid Below Pump
29	Insulation Atop Battery Section
30	Insulation on bottom of Battery Section
31	Fluid in Outside Circulation Loop
100	Environment

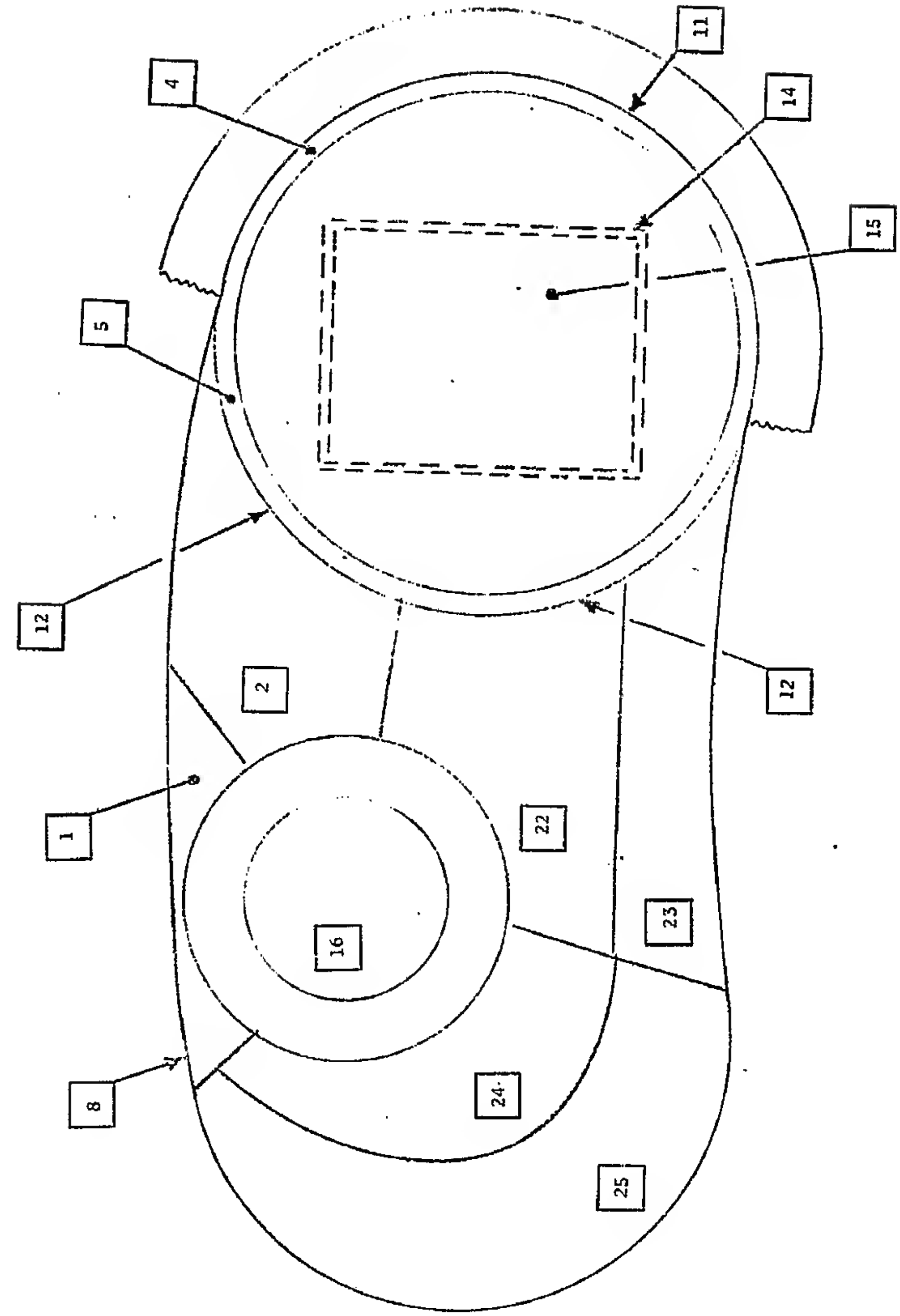


FIGURE 1-B: HEAT SINK MODEL - NODE DESCRIPTION - TOP VIEW

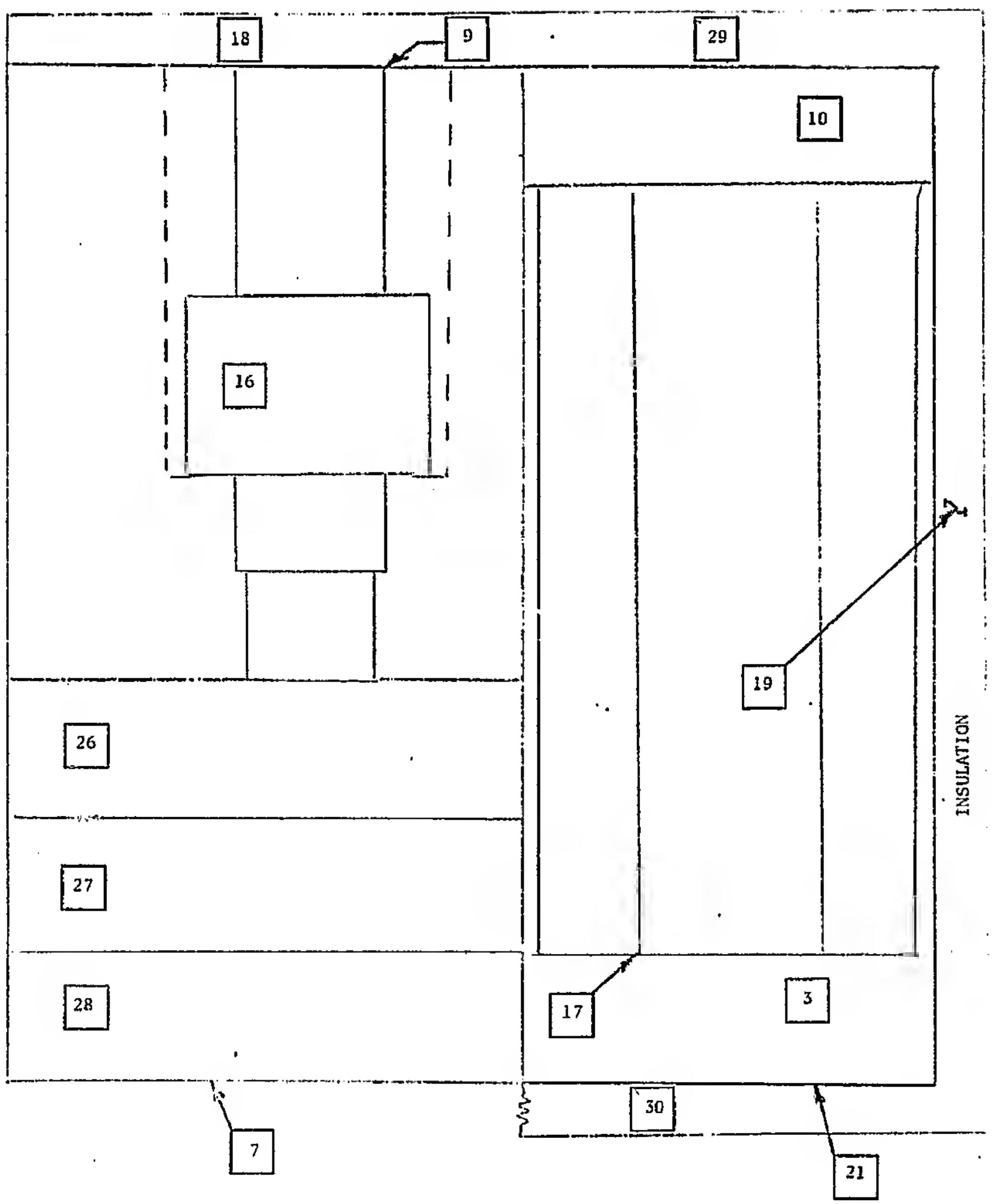
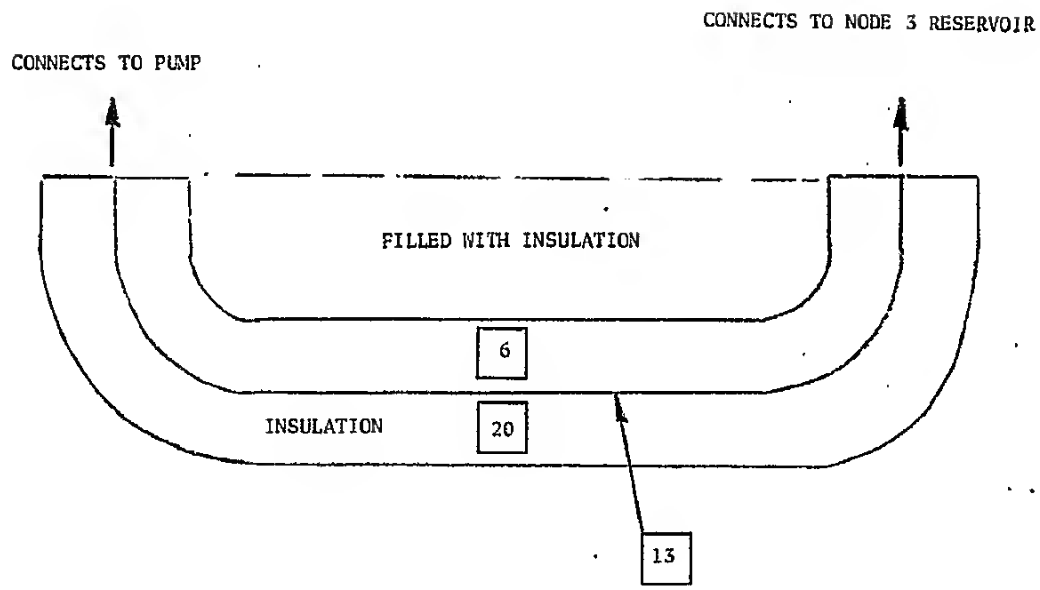


FIGURE 2-B: FUSIBLE HEAT SINK - NODE DESCRIPTION - SIDE VIEW COOLDOWN MODEL



COOLDOWN MODEL

FIGURE 3-B: FUSIBLE HEAT SINK - NODE DESCRIPTION - EXPANSION CIRCULATION TUBE

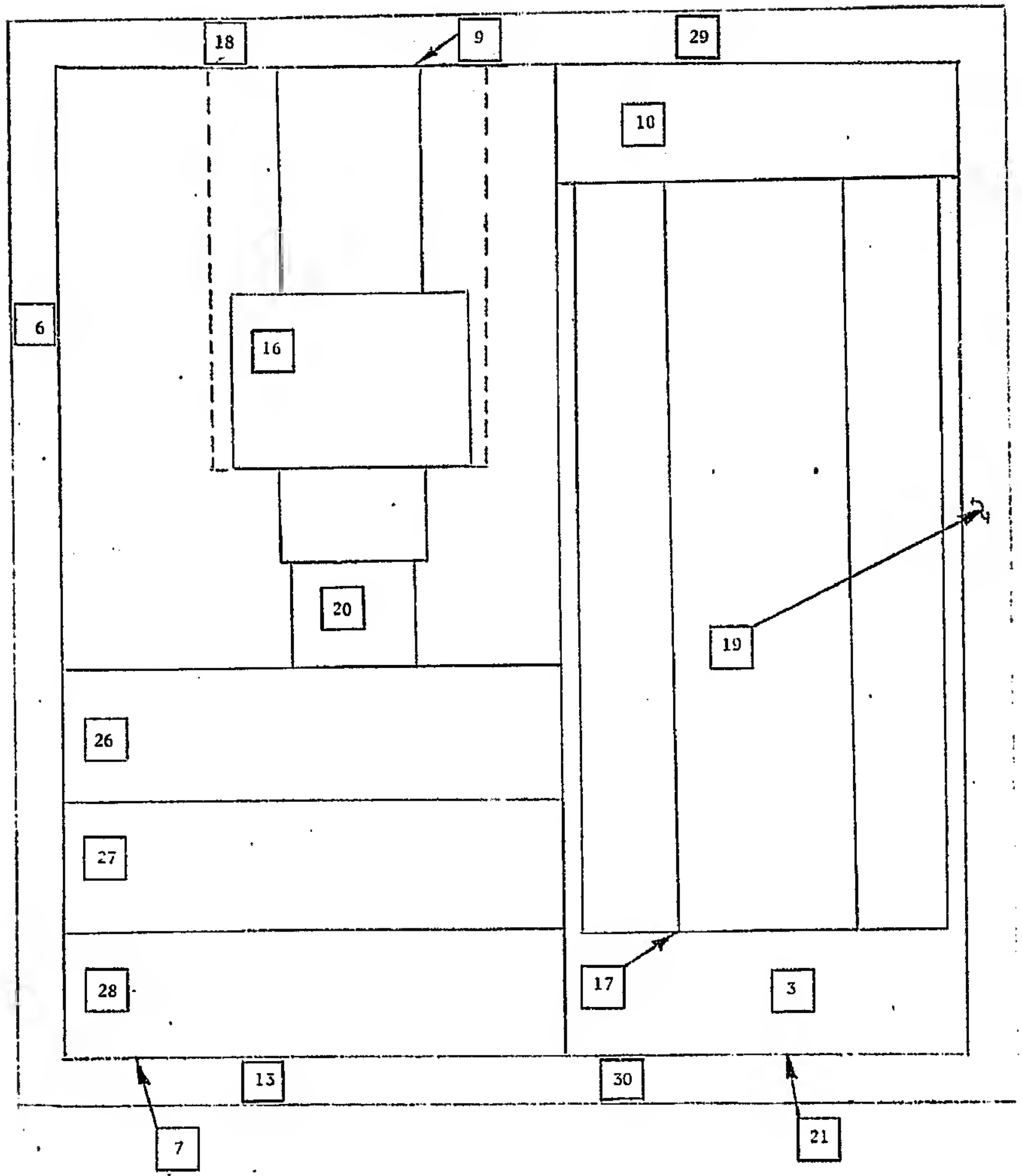


FIGURE 4-8: FUSIBLE HEAT SINK - NODE DESCRIPTION - SIDE VIEW WARMUP MODEL

COOLDOWN MODEL

COOLDOWN CASE

```
BCO 3THERMAL LPCS
BCO 9 TRANSIENT WATER/KHF2/ETHANOL FUSIBLE HEAT SINK
END
BCO 3NODE DATA
CGS 1,50.,A1,5.94          $ LIQUID AROUND PUMP
CGS 2,50.,A1,13.96         $ LIQUID AROUND PUMP
CGS 3,50.,A1,9.7           $ LIQUID BELOW BATTERY
CGS 4,50.,A1,3.43          $ LIQUID AROUND BLADDER
CGS 5,50.,A1,3.43          $ LIQUID AROUND BLADDER
CGS 6,50.,A1,.921          $ LIQUID IN TUBE
    7,50.,.0212            $ METAL S/S BOTTOM BELOW MOTOR
    8,50.,.171             $ METAL S/S SIDE MOTOR SECTION
    9,50.,.036             $ METAL S/S  TOP MOTOR SECTION
    10,50.,.059            $ METAL S/S TOP BATTERY SECTION
    11,50.,.067            $ METAL S/S OUTER SIDE BATTERY SECTION
    12,50.,.067            $ METAL S/S INNER SIDE BATTERY SECTION
    13,50.,.0133           $ METAL S/S TUBE
    14,50.,.0666           $ METAL S/S AROUND BATTERY
    15,50.,.528            $ BATTERY
    16,50.,.159            $ PUMP/MOTOR
    17,50.,.0127           $ METAL S/S BOTTOM OF BATTERY
    18,50.,.0159           $ INSULATION ATOP MOTOR SECTION
    19,50.,.0601           $ INSULATION SIDE OF BATTERY SECTION
    20,50.,.0236           $ INSULATION AROUND TUBE
    21,50.,.0127           $ METAL BOTTOM OF BATTERY SECTION
CGS 22,50.,A1,14.99        $ LIQUID AROUND PUMP
CGS 23,50.,A1,11.88        $ LIQUID AROUND PUMP
CGS 24,50.,A1,13.01        $ LIQUID AROUND PUMP
CGS 25,50.,A1,21.51        $ LIQUID AROUND PUMP
CGS 26,50.,A1,20.8         $ LIQUID BELOW PUMP
CGS 27,50.,A1,20.8         $ LIQUID BELOW PUMP
CGS 28,50.,A1,20.8         $ LIQUID BELOW PUMP
    29,50.,.0114           $ INSULATION ATOP BATTERY SECTION
    30,50.,.0114         $ INSULATION ON BOTTOM OF BATTERY SECTION
    -100,0.00,1.           $ ENVIRONMENT
END
```

NODE NUMBER, INITIAL TEMP. °F, ARRAY 1 FOR MULTIPLIER, THERMAL MASS mc_p BTU/°F

mc_p @ T = mc_p × MULTIPLIER

BOUNDARY CONDITION AT 0°F

RELATIVE NODE NUMBERS / ACTUAL NODE NUMBERS

RELATIVE NODE NUMBERS			ACTUAL NODE NUMBERS									
1	THRU	10	1	2	3	4	5	6	7	8	9	10
11	THRU	20	11	12	13	14	15	16	17	18	19	20
21	THRU	30	21	22	23	24	25	26	27	28	29	30
31	THRU	31	100									

PROGRAM RENUMBERING OF NODE NOT INPUT

```
BCO 3CONDUCTOR DATA
REM NOTE CGS CONDUCTOR CONSTANT VALUES FOR K=.375BTU-FT/HR-FT2-F
REM K=1.3 BTU-FT/HR-FT2-F AT 6.2F
REM K= .375 BTU-FT/HR-FT2-F AT 18.8F
CGS 10,3,12,A8,.184
CGS 11,3,17,A8,.604
CGS 12,3,6,A8,8.25E-4
CGS 13,3,11,A8,.184
CGS 14,3,21,A8,.604
CGS 15,4,11,A8,26.2
CGS 16,4,5,A8,9.5E-3
CGS 17,4,14,A8,.0931
CGS 18,5,12,A8,26.2
CGS 19,5,14,A8,.0931
```

COMMENT CARDS

```
CGS 21,6,13,A8,3.22
    22,7,21,.022
    23,7,8,.0456
    24,8,9,.0552
    25,8,13,2.8E-4
    26,9,18,.0697
    27,9,16,2.35E-3    $ CONDUCTANCE THRU PTFCE PLASTIC
    28,9,10,.0363
    29,10,11,.0285
    30,10,14,.0533
    31,10,12,.0285
    32,11,19,.467
    33,11,12,.994
    34,11,13,1.4E-4
    35,11,21,.0155
    36,13,12,1.4E-4
    37,13,20,.0858
    38,13,16,2.81E-4
    39,14,17,.0533
    40,14,15,109.1
    41,21,12,.0155
REM CONDUCTANCES FOR CONVECTION AT 1G
    42,100,7,.435      $ HA*3
    43,100,30,.0872
    44,100,8,3.522     $ HA*3
    45,100,19,.515
    46,100,29,.0872
    47,100,18,.145
    48,100,20,.1764
REM END CONDUCTANCES FOR 1G EXTERNAL CONVECTION
CGS 49,1,2,A8,.035
CGS 50,1,24,A8,.014
CGS 51,1,25,A8,.014
CGS 52,1,9,A8,.0151
CGS 53,1,8,A8,1.467
CGS 54,1,26,A8,.0122
CGS 55,1,16,A9,.0899    $ CONDUCTANCE FLUID AROUND PUMP TO PUMP
CGS 56,2,22,A8,.11
CGS 57,2,16,A10,.0539   $ CONDUCTANCE FLUID AROUND PUMP TO PUMP
CGS 58,2,12,A8,.428
CGS 59,2,26,A8,.0288
CGS 60,2,9,A8,.0355
CGS 61,2,8,A8,.24
CGS 62,22,23,A8,.5
CGS 63,22,24,A8,.064
CGS 64,22,25,A8,.0309
CGS 65,22,12,A8,.425
CGS 66,22,16,A11,.095   $ CONDUCTANCE FLUID AROUND PUMP TO PUMP
CGS 67,22,9,A8,.0382
CGS 68,23,12,A8,.1066
CGS 69,23,26,A8,.0245
CGS 70,23,25,A8,.067
CGS 71,23,8,A8,1.6
CGS 72,23,9,A8,.0302
CGS 73,24,15,A12,.1163 $ CONDUCTANCE FLUID AROUND PUMP TO PUMP
CGS 74,24,25,A8,.6
CGS 75,24,9,A8,.0331
CGS 76,24,26,A8,.0268
CGS 77,25,8,A8,1.67
CGS 78,25,26,A8,.0443
```

CONDUCTOR NUMBER, NODE #, NODE #, ARRAY 8 FOR MULTIPLIER, CONDUCTANCE G BTU/HR-°F

G @ T = G x MULTIPLIER

```
CGS 80,26,27,A8,.466
CGS 81,26,16,A8,.0548
CGS 82,26,12,A8,.0325
CGS 83,26,8,A8,.37
CGS 84,27,28,A8,.466
CGS 85,27,8,A8,.37
CGS 86,27,12,A8,.0325
CGS 87,28,7,A8,.932
CGS 88,28,8,A8,.37
CGS 89,28,12,A8,.0325
    90,18,29,7.41E-4
    91,29,19,.01645
    92,19,29,8.75E-4
    93,30,21,.0419
    94,30,19,8.75E-4
REM RADIATION CONDUCTORS
    -100,4,14,2.05E-10
    -101,5,14,2.05E-10
    -102,100,7,2.49E-10
    -103,100,30,.0747E-10    $ INSULATION E=.05
    -104,100,8,20.1E-10
    -105,100,19,.441E-10     $ INSULATION E=.05
    -106,100,29,.0747E-10    $ INSULATION E=.05
    -107,100,18,.124E-10     $ INSULATION E=.05
    -108,100,20,.151E-10     $ INSULATION E=.05
END
```

RADIATION CONDUCTORS

RELATIVE CONDUCTOR NUMBERS — ACTUAL CONDUCTOR NUMBERS

1	THRU	10	10	11	12	13	14	15	16	17	18	19
11	THRU	20	20	21	22	23	24	25	26	27	28	29
21	THRU	30	30	31	32	33	34	35	36	37	38	39
31	THRU	40	40	41	42	43	44	45	46	47	48	49
41	THRU	50	50	51	52	53	54	55	56	57	58	59
51	THRU	60	60	61	62	63	64	65	66	67	68	69
61	THRU	70	70	71	72	73	74	75	76	77	78	79
71	THRU	80	80	81	82	83	84	85	86	87	88	89
81	THRU	90	90	91	92	93	94	100	101	102	103	104
91	THRU	94	105	106	107	108						

PROGRAM RENUMBERING OF CONDUCTORS NOT INPUT

```
BCO 3CONSTANTS DATA
    TIMEND,96.,OUTPUT,1.0
    DTIMEI,.1
    NLOOP,3000
    DRLXCA,.05,ARLXCA,.05
    1,0.,2,0.,3,0.,4,0.,5,0.,6,0.,7,0.,8,0.,9,0.
    10,0.,11,0.,12,0.,13,0.,14,0.,15,0.,16,0.,17,0.,18,0.
END
BCO 3ARRAY DATA
    1,-50.,.0457,6.19,.0457,6.20,1.0,18.79,1.0,18.8,.0457
    100.,.0457,END
    -2,QRRATE,QRTOT,QCRATE,QCTOT,END
    -4,C1,C2,C22,C23,END
    -5,C24,C25,C26,C27,END
    -6,C28,C3,C4,C5,END
    -7,C6,G53,G62,END
REM NOTE CHANGE IN ARRAY DATA 8 THRU 12
    8,-50.,3.47,6.20,3.47,18.80,1.0,100.,1.0,END
    9,-50.,1.36,6.200,1.36,18.80,1.0,100.,1.0,END
    10,-50.,2.03,6.200,2.03,18.80,1.0,100.,1.0,END
    11,-50.,1.78,6.200,1.78,18.80,1.0,100.,1.0,END
```

RUNNING TIME FOR PROBLEM HOURS, OUTPUT PRINTOUT INTERVAL HOURS

INPUT REQ'D FOR TRANSIENT ROUTINE CNFWBK (EXECUTION BLOCK)

INITIALIZING CONSTANTS USED IN VARIABLES 2

ARRAY NUMBER (TEMP, MULTIPLIER, TEMP MULTIPLIER...

LABEL ARRAY CALLED FROM OUTPUT CALLS

```
 END
 BCD 3EXECUTION
DIMENSION X(200)                                                      F      INDICATES SIZE OF PROGRAM
NDIM=200                                                              F
NTH=0                                                                 F
      CSGDMP                                                          CALL FOR ORDERED NODE-CONDUCTANCE PRINT
      CNFWBK                                                           TRANSIENT ROUTINE
 END
 BCD 3VARIABLES 1
      VARCSM(T    1,C     1,A1,5.94)
      VARCSM(T    2,C     2,A1,13.96)
      VARCSM(T    3,C     3,A1,9.7)
      VARCSM(T    4,C     4,A1,3.43)
      VARCSM(T    5,C     5,A1,3.43)
      VARCSM(T    6,C     6,A1,.921)
      VARCSM(T   22,C    22,A1,14.99)
      VARCSM(T   23,C    23,A1,11.88)
      VARCSM(T   24,C    24,A1,13.01)
      VARCSM(T   25,C    25,A1,21.51)
      VARCSM(T   26,C    26,A1,20.8)
      VARCSM(T   27,C    27,A1,20.8)
      VARCSM(T   28,C    28,A1,20.8)
      VARGSM(G   10,T     3,T   12,A8,.184)
      VARGSM(G   11,T     3,T   17,A8,.604)
      VARGSM(G   12,T     3,T    6,A8,8.25E-4)
      VARGSM(G   13,T     3,T   11,A8,.184)
      VARGSM(G   14,T     3,T   21,A8,.604)                                DONE BY PROGRAM - NOT INPUT
      VARGSM(G   15,T     4,T   11,A8,26.2)
      VARGSM(G   16,T     4,T    5,A8,9.5E-3)
      VARGSM(G   17,T     4,T   14,A8,.0931)
      VARGSM(G   18,T     5,T   12,A8,26.2)
      VARGSM(G   19,T     5,T   14,A8,.0931)
      VARGSM(G   20,T     6,T   16,A8,8.25E-4)
      VARGSM(G   21,T     6,T   13,A8,3.22)
      VARGSM(G   49,T     1,T    2,A8,.035)
      VARGSM(G   50,T     1,T   24,A8,.014)
      VARGSM(G   51,T     1,T   25,A8,.014)
      VARGSM(G   52,T     1,T    9,A8,.0151)
      VARGSM(G   53,T     1,T    8,A8,1.467)
      VARGSM(G   54,T     1,T   26,A8,.0122)
      VARGSM(G   55,T     1,T   16,A9,.0899)
      VARGSM(G   56,T     2,T   22,A8,.11)
      VARGSM(G   57,T     2,T   16,A10,.0539)
      VARGSM(G   58,T     2,T   12,A8,.428)
      VARGSM(G   59,T     2,T   26,A8,.0288)
      VARGSM(G   60,T     2,T    9,A8,.0355)
      VARGSM(G   61,T     2,T    8,A8,.24)
      VARGSM(G   62,T    22,T   23,A8,.5)
      VARGSM(G   63,T    22,T   24,A8,.064)
      VARGSM(G   64,T    22,T   26,A8,.0309)
      VARGSM(G   65,T    22,T   12,A8,.425)
      VARGSM(G   66,T    22,T   16,A11,.095)
      VARGSM(G   67,T    22,T    9,A8,.0382)
      VARGSM(G   68,T    23,T   12,A8,.1066)
      VARGSM(G   69,T    23,T   26,A8,.0245)
      VARGSM(G   70,T    23,T   25,A8,.067)
      VARGSM(G   71,T    23,T    8,A8,1.6)
      VARGSM(G   72,T    23,T    9,A8,.0302)
      VARGSM(G   73,T    24,T   16,A12,.1163)
      VARGSM(G   74,T    24,T   25,A8,.6)
```

```
     VARGSM(G   76,T   24,T   26,A8,.026R)
     VARGSM(G   77,T   25,T    8,A8,1.67)
     VARGSM(G   78,T   25,T   26,A8,.0443)
     VARGSM(G   79,T   25,T    9,A8,.0547)
     VARGSM(G   80,T   26,T   27,A8,.466)
     VARGSM(G   81,T   26,T   16,A8,.0548)
     VARGSM(G   82,T   26,T   12,A8,.0325)
     VARGSM(G   83,T   26,T    8,A8,.37)
     VARGSM(G   84,T   27,T   28,A8,.466)
     VARGSM(G   85,T   27,T    8,A8,.37)
     VARGSM(G   86,T   27,T   12,A8,.0325)
     VARGSM(G   87,T   28,T    7,A8,.932)
     VARGSM(G   88,T   28,T    8,A8,.37)
     VARGSM(G   89,T   28,T   12,A8,.0325)
ENDV1
     STFSEP(3.41,Q13)   $ 1 WATT ARDUND TUBE                  <---- PLACES 3.41 BTU/HR IN NODE 13
     STFSEP(.201,G53)   $ AIR GAP  .05 IN NDOE 1 TO NODE 8    <---- PLACES .201 BTU/HR-°F IN CONDUCTOR 53
END
BCD 3VARIABLES 2
     QMETER(T7,T100,G42,K10)     <---- PLACES Q = G(42) x (T(7) - T(100)) INTO CONSTANT LOCATION K10
     QMETER(T30,T100,G43,K11)
     QMETER(T8,T100,G44,K12)
     QMETER(T19,T100,G45,K13)
     QMETER(T29,T100,G46,K14)
     QMETER(T18,T100,G47,K15)
     QMETER(T20,T100,G48,K16)
     ADD(K10,K11,K12,K13,K14,K15,K16,K17)   <---- ADDS K'S AND PUTS SUM IN K17
     QINTEG(K17,DTIMEU,K18)  $ INTEGRATE CONVECTION HEAT FLOW  <---- SUMS HEAT FOR EACH TIME STEP
     RDTNQS(T100,T7,G102,K1)
     RDTNQS(T100,T30,G103,K2)    <---- PLACES Q = G(103) x (T^4(30) - T^4(100)) INTO K2
     RDTNQS(T100,T8,G104,K3)
     RDTNQS(T100,T19,G105,K4)
     RDTNQS(T100,T29,G106,K5)
     RDTNQS(T100,T18,G107,K6)
     RDTNQS(T100,T20,G108,K7)
     ADD(K1,K2,K3,K4,K5,K6,K7,K8)
     QINTEG(K8,DTIMEU,K9)     $ INTEGRATE RADIATION HEAT FLOW
END
BCD 3OUTPUT CALLS
     PRNTMP       <---- PRINTS ALL NODE TEMPERATURES
     PRINTL(A2,K8,K9,K17,K18)   <---- PRINTS LABELS FROM ARRAY 2 FOR CONSTANTS IN SEQUENCE
     PRINTL(A4,C1,C2,C22,C23)
     PRINTL(A5,C24,C25,C26,C27)
     PRINTL(A6,C28,C3,C4,C5)
     PRINTL(A7,C6,G53,G62)
END
```

TRANSIENT WATER/KHF2/ETHANOL FUSIBLE HEAT SINK

* * * *
TIME, 0.0 DTIMEU 0.0 CSGMIN(0) 0.0 DTMPCC(0) 0.0 ARLXCC(0) 0.0

1 THRU	5	5.000000E 01	5.000000E 01	5.000000E 01	5.000000E 01	5.000000E 01
6 THRU	10	5.000000E 01	5.000000E 01	5.000000E 01	5.000000E 01	5.000000E 01
11 THRU	15	5.000000E 01	5.000000E 01	5.000000E 01	5.000000E 01	5.000000E 01
16 THRU	20	5.000000E 01	5.000000E 01	5.000000E 01	5.000000E 01	5.000000E 01
21 THRU	25	5.000000E 01	5.000000E 01	5.000000E 01	5.000000E 01	5.000000E 01
26 THRU	30	5.000000E 01	5.000000E 01	5.000000E 01	5.000000E 01	5.000000E 01
31 THRU	31	0.0				

QRRA 0.0 QRTO 0.0 QCRA 0.0 QCTO 0.0

C1 0.27146E 00 C2 0.63797E 00 C22 0.68504E 00 C23 0.54292E 00

C24 0.59456E 00 C25 0.98301E 00 C26 0.95056E 00 C27 0.95056E 00

C28 0.95056E 00 C3 0.44329E 00 C4 0.15675E 00 C5 0.15675E 00

C6 0.42090E-01 G53 0.20100E 00 G62 0.50000E 00

B-14

A 30 NODE PROBLEM USING LPCS
NODE 14 HAS THE CSGMIN OF 6.07607E-04, NODE 26 HAS THE CSGMAX OF 8.71434E-01

WHAT FOLLOWS IS THE RESULT OF CSGDMP CALL IN EXECUTION BLOCK

CONDUCTANCE G IN BTU/HR-°F

C BTU/°F — C/ΣG HOURS — RELATIVE CONDUCTOR NUMBER

NODE	C-VALUE	CSG-VALUE	COND	TYPE	G-VALUE	TO NODE	TYPE
1	2.715E-01	7.121E-01					
			40	LIN	3.500E-02	2	DIFF
			41	LIN	1.400E-02	24	DIFF
			42	LIN	1.400E-02	25	DIFF
			43	LIN	1.510E-02	9	DIFF
			44	LIN	2.010E-01	8	DIFF
			45	LIN	1.220E-02	26	DIFF
			46	LIN	8.990E-02	16	DIFF
2	6.380E-01	5.851E-01					
			40	LIN	3.500E-02	1	DIFF
			47	LIN	1.100E-01	22	DIFF
			48	LIN	5.390E-02	16	DIFF
			49	LIN	4.280E-01	12	DIFF
			50	LIN	2.880E-02	26	DIFF
			51	LIN	3.550E-02	9	DIFF
			52	LIN	2.400E-01	8	DIFF
3	4.433E-01	2.811E-01					
			1	LIN	1.840E-01	12	DIFF
			2	LIN	6.040E-01	17	DIFF
			3	LIN	8.250E-04	6	DIFF
			4	LIN	1.840E-01	11	DIFF
			5	LIN	6.040E-01	21	DIFF
4	1.568E-01	5.935E-03					
			6	LIN	2.620E 01	11	DIFF
			7	LIN	9.500E-03	5	DIFF
			8	LIN	9.310E-02	14	DIFF
			86	RAD	2.050E-10	14	DIFF
5	1.568E-01	5.935E-03					
			7	LIN	9.500E-03	4	DIFF
			9	LIN	2.620E 01	12	DIFF
			10	LIN	9.310E-02	14	DIFF

6 4.209E-02 1.306E-02

3 LIN 8.250E-04 3 DIFF

TRANSIENT WATER/KHF2/ETHANOL FUSIBLE HEAT SINK

			11	LIN	8.250E-04	16	DIFF
7	2.120E-02	1.369E-02	12	LIN	3.220E 00	13	DIFF
			13	LIN	2.200E-02	21	DIFF
			14	LIN	4.560E-02	8	DIFF
			33	LIN	4.350E-01	31	BOUN
			78	LIN	9.320E-01	28	DIFF
8	1.710E-01	1.826E-02	88	RAD	2.490E-10	31	BOUN
			14	LIN	4.560E-02	7	DIFF
			15	LIN	5.520E-02	9	DIFF
			16	LIN	2.800E-04	13	DIFF
			35	LIN	3.522E 00	31	BOUN
			44	LIN	2.010E-01	1	DIFF
			52	LIN	2.400E-01	2	DIFF
			62	LIN	1.600E 00	23	DIFF
			68	LIN	1.670E 00	25	DIFF
			74	LIN	3.700E-01	26	DIFF
			76	LIN	3.700E-01	27	DIFF
			79	LIN	3.700E-01	28	DIFF
9	3.600E-02	9.721E-02	90	RAD	2.010E-09	31	BOUN
			15	LIN	5.520E-02	8	DIFF
			17	LIN	6.970E-02	18	DIFF
			18	LIN	2.350E-03	16	DIFF
			19	LIN	3.630E-02	10	DIFF
			43	LIN	1.510E-02	1	DIFF
			51	LIN	3.550E-02	2	DIFF
			58	LIN	3.820E-02	22	DIFF
			63	LIN	3.020E-02	23	DIFF
			66	LIN	3.310E-02	24	DIFF
10	5.900E-02	3.619E-01	70	LIN	5.470E-02	25	DIFF
			19	LIN	3.630E-02	9	DIFF
			20	LIN	2.850E-02	11	DIFF
			21	LIN	5.330E-02	14	DIFF
			22	LIN	2.850E-02	12	DIFF
11	6.700E-02	2.402E-03	02	LIN	1.645E-02	29	DIFF
			4	LIN	1.840E-01	3	DIFF
			6	LIN	2.620E 01	4	DIFF
			20	LIN	2.850E-02	10	DIFF
			23	LIN	4.670E-01	19	DIFF
			24	LIN	9.940E-01	12	DIFF
			25	LIN	1.400E-04	13	DIFF
12	6.700E-02	2.353E-03	26	LIN	1.550E-02	21	DIFF
			1	LIN	1.840E-01	3	DIFF
			9	LIN	2.620E 01	5	DIFF

(9)

TRANSIENT WATER/KHF2/ETHANOL FUSIBLE HEAT SINK

```
                                22  LIN 2.850E-02   10 DIFF
                                24  LIN 9.940E-01   11 DIFF
                                27  LIN 1.400E-04   13 DIFF
                                32  LIN 1.550E-02   21 DIFF
                                49  LIN 4.280E-01    2 DIFF
                                56  LIN 4.250E-01   22 DIFF
                                59  LIN 1.066E-01   23 DIFF
                                73  LIN 3.250E-02   26 DIFF
                                77  LIN 3.250E-02   27 DIFF
                                80  LIN 3.250E-02   28 DIFF
13 1.330E-02 4.022E-03
                                12  LIN 3.220E 00    6 DIFF
                                16  LIN 2.800E-04    8 DIFF
                                25  LIN 1.400E-04   11 DIFF
                                27  LIN 1.400E-04   12 DIFF
                                28  LIN 8.580E-02   20 DIFF
                                29  LIN 2.810E-04   16 DIFF
14 6.660E-02 6.076E-04
                                 8  LIN 9.310E-02    4 DIFF
                                10  LIN 9.310E-02    5 DIFF
                                21  LIN 5.330E-02   10 DIFF
                                30  LIN 5.330E-02   17 DIFF
                                31  LIN 1.091E 02   15 DIFF
                                86  RAD 2.050E-10    4 DIFF
                                87  RAD 2.050E-10    5 DIFF
15 5.280E-01 4.840E-03
                                31  LIN 1.091E 02   14 DIFF
16 1.590E-01 3.847E-01
                                11  LIN 8.250E-04    6 DIFF
                                18  LIN 2.350E-03    9 DIFF
                                29  LIN 2.810E-04   13 DIFF
                                46  LIN 8.990E-02    1 DIFF
                                48  LIN 5.390E-02    2 DIFF
                                57  LIN 9.500E-02   22 DIFF
                                64  LIN 1.163E-01   24 DIFF
                                72  LIN 5.480E-02   26 DIFF
17 1.270E-02 1.932E-02
                                 2  LIN 6.040E-01    3 DIFF
                                30  LIN 5.330E-02   14 DIFF
18 1.590E-02 7.191E-02
                                17  LIN 6.970E-02    9 DIFF
                                38  LIN 1.450E-01   31 BOUN
                                81  LIN 7.410E-04   29 DIFF
                                93  RAD 1.240E-11   31 BOUN
19 6.010E-02 5.986E-02
                                23  LIN 4.670E-01   11 DIFF
                                36  LIN 5.150E-01   31 BOUN
                                83  LIN 8.750E-04   29 DIFF
                                85  LIN 8.750E-04   30 DIFF
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   TRANSIENT WATER/KHF2/ETHANOL FUSIBLE HEAT SINK
                              91  RAD 4.410E-11   31 BOUN
 20 2.360E-02 8.770E-02
                              28  LIN 8.580E-02   13 DIFF
                              39  LIN 1.764E-01   31 BOUN
                              94  RAD 1.510E-11   31 BOUN
 21 1.270E-02 1.817E-02
                               5  LIN 6.040E-01    3 DIFF
                              13  LIN 2.200E-02    7 DIFF
                              26  LIN 1.550E-02   11 DIFF
                              32  LIN 1.550E-02   12 DIFF
                              84  LIN 4.190E-02   30 DIFF
 22 6.850E-01 5.424E-01
                              47  LIN 1.100E-01    2 DIFF
                              53  LIN 5.000E-01   23 DIFF
                              54  LIN 6.400E-02   24 DIFF
                              55  LIN 3.090E-02   26 DIFF
                              56  LIN 4.250E-01   12 DIFF
                              57  LIN 9.500E-02   16 DIFF
                              58  LIN 3.820E-02    9 DIFF
 23 5.429E-01 2.332E-01
                              53  LIN 5.000E-01   22 DIFF
                              59  LIN 1.066E-01   12 DIFF
                              60  LIN 2.450E-02   26 DIFF
                              61  LIN 6.700E-02   25 DIFF
                              62  LIN 1.6[illegible]0E 00    8 DIFF
                              63  LIN 3.020E-02    9 DIFF
 24 5.946E-01 6.960E-01
                              41  LIN 1.400E-02    1 DIFF
                              54  LIN 6.400E-02   22 DIFF
                              64  LIN 1.163E-01   16 DIFF
                              65  LIN 6.000E-01   25 DIFF
                              66  LIN 3.310E-02    9 DIFF
                              67  LIN 2.680E-02   26 DIFF
 25 9.830E-01 4.012E-01
                              42  LIN 1.400E-02    1 DIFF
                              61  LIN 6.700E-02   23 DIFF
                              65  LIN 6.000E-01   24 DIFF
                              68  LIN 1.670E 00    8 DIFF
                              69  LIN 4.430E-02   26 DIFF
                              70  LIN 5.470E-02    9 DIFF
 26 9.506E-01 8.714E-01
                              45  LIN 1.220E-02    1 DIFF
                              50  LIN 2.880E-02    2 DIFF
                              55  LIN 3.090E-02   22 DIFF
                              60  LIN 2.450E-02   23 DIFF
                              67  LIN 2.680E-02   24 DIFF
                              69  LIN 4.430E-02   25 DIFF
                              71  LIN 4.660E-01   27 DIFF
                              72  LIN 5.480E-02   16 DIFF
```

```
    TRANSIENT WATER/KHF2/ETHANOL FUSIBLE HEAT SINK
                         73  LIN 3.250E-02   12 DIFF
                         74  LIN 3.700E-01    8 DIFF
 27 9.506E-01 7.123E-01
                         71  LIN 4.660E-01   26 DIFF
                         75  LIN 4.660E-01   28 DIFF
                         76  LIN 3.700E-01    8 DIFF
                         77  LIN 3.250E-02   12 DIFF
 28 9.506E-01 5.279E-01
                         75  LIN 4.660E-01   27 DIFF
                         78  LIN 9.320E-01    7 DIFF
                         79  LIN 3.700E-01    8 DIFF
                         80  LIN 3.250E-02   12 DIFF
 29 1.140E-02 1.049E-01
                         37  LIN 8.720E-02   31 BOUN
                         81  LIN 7.410E-04   18 DIFF
                         82  LIN 1.645E-02   10 DIFF
                         83  LIN 8.750E-04   19 DIFF
                         92  RAD 7.470E-12   31 BOUN
 30 1.140E-02 8.546E-02
                         34  LIN 8.720E-02   31 BOUN
                         84  LIN 4.190E-02   21 DIFF
                         85  LIN 8.750E-04   19 DIFF
                         89  RAD 7.470E-12   31 BOUN

 * * * *
 TIME  0.0      DTIMEU  0.0      CSGMIN(    0)  0.0      DTMPCC(    0)  0.0      ARLXCC(    0)  0.0

     1  THRU   5    5.000000E 01   5.000000E 01   5.000000E 01   5.000000E 01   5.000000E 01
     6  THRU  10    5.000000E 01   5.000000E 01   5.000000E 01   5.000000E 01   5.000000E 01
    11  THRU  15    5.000000E 01   5.000000E 01   5.000000E 01   5.000000E 01   5.000000E 01
    16  THRU  20    5.000000E 01   5.000000E 01   5.000000E 01   5.000000E 01   5.000000E 01
    21  THRU  25    5.000000E 01   5.000000E 01   5.000000E 01   5.000000E 01   5.000000E 01
    26  THRU  30    5.000000E 01   5.000000E 01   5.000000E 01   5.000000E 01   5.000000E 01
    31  THRU  31    0.0

 QRRA   0.0        QRTO   0.0        QCRA   0.0        QCTO   0.0

 C1     0.27146E 00 C2    0.63797E 00 C22   0.68504E 00 C23   0.54292E 00

 C24    0.59456E 00 C25   0.98301E 00 C26   0.95056E 00 C27   0.95056E 00

 C28    0.95056E 00 C3    0.44329E 00 C4    0.15675E 00 C5    0.15675E 00

 C6     0.42090E-01 G53   0.20100E 00 G62   0.50000E 00

 * * * *
 TIME  1.00000E 00 DTIMEU  5.00002E-02 CSGMIN(   14)  6.07658E-04 DTMPCC(   28)  6.68213E-01 ARLXCC(    5)  1.46484E-03

     1  THRU   5    3.557642E 01   3.989941E 01   4.325879E 01   3.559595E 01   3.901025E 01
     6  THRU  10    5.668652E 01   2.015356E 01   1.593970E 01   2.822119E 01   3.822583E 01
    11  THRU  15    3.547729E 01   3.890015E 01   5.686987E 01   4.568579E 01   4.571655E 01
    16  THRU  20    4.322974E 01   4.361084E 01   9.168701E 00   1.677246E 01   1.810571E 01
    21  THRU  25    4.059937E 01   3.999756E 01   2.518628E 01   4.032666E 01   2.791846E 01
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(12)

TRANSIENT WATER/KHF2/ETHANOL FUSIBLE HEAT SINK

6	THRU	10	5.669922E 01	1.181787E 01	1.020386E 01	1.360669E 01	1.467993E 01
11	THRU	15	1.564355E 01	1.701563E 01	5.671924E 01	1.696167E 01	1.696729E 01
16	THRU	20	1.769189E 01	1.816113E 01	4.316650E 00	7.315186E 00	1.812866E 01
21	THRU	25	1.735522E 01	1.758765E 01	1.277612E 01	1.772168E 01	1.399927E 01
26	THRU	30	1.725806E 01	1.714331E 01	1.511572E 01	2.325928E 00	5.520752E 00
31	THRU	31	0.0				

QRRA	0.97315E 01	QRTO	0.10694E 03	QCRA	0.49354E 02	QCTO	0.54208E 03
C1	0.59400E 01	C2	0.13960E 02	C22	0.14990E 02	C23	0.11880E 02
C24	0.13010E 02	C25	0.21510E 02	C26	0.20800E 02	C27	0.20800E 02
C28	0.20800E 02	C3	0.97000E 01	C4	0.34300E 01	C5	0.34300E 01
C6	0.42090E-01	G53	0.20100E 00	G62	0.85286E 00		

* * * *

TIME 1.00000E 01 DTIMEU 5.00002E-02 CSGMIN(14) 6.07253E-04 DTMPCC(14) 3.41797E-02 ARLXCC(14) 3.90625E-03

NODES TEMPERATURES °F

1	THRU	5	1.708105E 01	1.723267E 01	1.806055E 01	1.526465E 01	1.665259E 01
6	THRU	10	5.668555E 01	1.157373E 01	9.987549E 00	1.333472E 01	1.427466E 01
11	THRU	15	1.522778E 01	1.661890E 01	5.670581E 01	1.645996E 01	1.646509E 01
16	THRU	20	1.739771E 01	1.795068E 01	4.230469E 00	7.119873E 00	1.812427E 01
21	THRU	25	1.718408E 01	1.726416E 01	1.239551E 01	1.741504E 01	1.350879E 01
26	THRU	30	1.698169E 01	1.682349E 01	1.470166E 01	2.260742E 00	5.465576E 00
31	THRU	31	0.0				

TOTAL RADIATION LOST, BTU — TOTAL CONVECTION LOST, BTU

QRRA	0.95210E 01	QRTO	0.11655E 03	QCRA	0.48362E 02	QCTO	0.59088E 03
C1	0.59400E 01	C2	0.13960E 02	C22	0.14990E 02	C23	0.11880E 02
C24	0.13010E 02	C25	0.21510E 02	C26	0.20800E 02	C27	0.20800E 02
C28	0.20800E 02	C3	0.97000E 01	C4	0.34300E 01	C5	0.34300E 01
C6	0.42090E-01	G53	0.20100E 00	G62	0.88748E 00		

THERMAL MASSES C(N), BTU/°F

CONDUCTANCES G(N), BTU/HR-°F

B-20

* * * *

TIME 1.10000E 01 DTIMEU 5.00002E-02 CSGMIN(14) 6.07166E-04 DTMPCC(15) 2.31934E-02 ARLXCC(14) 3.41797E-03

1	THRU	5	1.681274E 01	1.693042E 01	1.785229E 01	1.489502E 01	1.628271E 01
6	THRU	10	5.668213E 01	1.133105E 01	9.785400E 00	1.307397E 01	1.392383E 01
11	THRU	15	1.486304E 01	1.625391E 01	5.670190E 01	1.602246E 01	1.602319E 01
16	THRU	20	1.708960E 01	1.772998E 01	4.146484E 00	6.948486E 00	1.812329E 01
21	THRU	25	1.700049E 01	1.692358E 01	1.206616E 01	1.708301E 01	1.306616E 01
26	THRU	30	1.669727E 01	1.649585E 01	1.430176E 01	2.205078E 00	5.406982E 00
31	THRU	31	0.0				

QRRA	0.93233E 01	QRTO	0.12596E 03	QCRA	0.47434E 02	QCTO	0.63873E 03
C1	0.59400E 01	C2	0.13960E 02	C22	0.14990E 02	C23	0.11880E 02

```
C28      0.20800E 02 C3       0.97000E 01 C4       0.34300E 01 C5       0.34300E 01

C6       0.42090E-01 G53      0.20100E 00 G62      0.11482E 01
```

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* * * *
TIME  2.00000E 01 OTIMEU  5.00002E-02 CSGMIN(   14)   6.06610E-04 DTMPCC(   15)   1.85547E-02 ARLXCC(   14)   5.37109E-03


       1  THRU     5      1.440356E 01      1.414087E 01      1.561255E 01      1.258703E 01      1.362622E 01
       6  THRU    10      5.657788E 01      9.363037E 00      8.307129E 00      1.101025E 01      1.166333E 01
      11  THRU    15      1.256567E 01      1.361035E 01      5.659937E 01      1.338525E 01      1.338501E 01
      16  THRU    20      1.414111E 01      1.550122E 01      3.492920E 00      5.872559E 00      1.809033E 01
      21  THRU    25      1.501245E 01      1.382544E 01      1.000391E 01      1.370874E 01      1.038599E 01
      26  THRU    30      1.398950E 01      1.349341E 01      1.135645E 01      1.845703E 00      4.775391E 00
      31  THRU    31      0.0

QRRA     0.78672E 01 QRTO     0.20293E 03 QCRA     0.40630E 02 QCTO     0.10332E 04

C1       0.59400E 01 C2       0.13960E 02 C22      0.14990E 02 C23      0.11880E 02

C24      0.13010E 02 C25      0.21510E 02 C26      0.20800E 02 C27      0.20800E 02

C28      0.20800E 02 C3       0.97000E 01 C4       0.34300E 01 C5       0.34300E 01

C6       0.42090E-01 G53      0.20100E 00 G62      0.11737E 01
```

```
* * * *
TIME  2.10000E 01 OTIMEU  5.00002E-02 CSGMIN(   14)   6.06556E-04 OTMPCC(   24)   1.80664E-02 ARLXCC(   14)   1.12305E-02


       1  THRU     5      1.414087E 01      1.383716E 01      1.534497E 01      1.236426E 01      1.335962E 01
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TRANSIENT WATER/KHF2/ETHANOL FUSIBLE HEAT SINK
  6 THRU 10    5.647607E 01   7.764160E 00   7.045410E 00   9.[illegible]89941E 00   9.783203E 00
 11 THRU 15    1.065381E 01   1.130542E 01   5.649878E 01   1.[illegible]23291E 01   1.123096E 01
 16 THRU 20    1.147461E 01   1.309009E 01   2.914551E 00   4.980225E 00   1.805786E 01
 21 THRU 25    1.275903E 01   1.120630E 01   8.399902E 00   1.080566E 01   8.589355E 00
 26 THRU 30    1.134106E 01   1.083154E 01   9.209717E 00   1.548828E 00   4.060059E 00
 31 THRU 31    0.0

QRRA   0.66437E 01 QRTO   0.26808E 03 QCRA   0.34853E 02 QCTO   0.13722E 04

C1     0.59400E 01 C2     0.13960E 02 C22    0.14990E 02 C23    0.11880E 02

C24    0.13010E 02 C25    0.21510E 02 C26    0.20800E 02 C27    0.20800E 02

C28    0.20800E 02 C3     0.97000E 01 C4     0.34300E 01 C5     0.34300E 01

C6     0.42090E-01 G53    0.20100E 00 G62    0.13808E 01

* * * *
TIME  3.00000E 01 DTIMEU  5.00002E-02 CSGMIN(   14)  6.06088E-04 DTMPCC(   14)  1.80664E-02 ARLXCC(   14)  1.95313E-03

  1 THRU  5    1.185083E 01   1.129492E 01   1.289380E 01   1.045923E 01   1.107397E 01
  6 THRU 10    5.646460E 01   7.603027E 00   6.910400E 00   8.998779E 00   9.582764E 00
 11 THRU 15    1.044653E 01   1.106274E 01   5.648730E 01   1.099780E 01   1.100073E 01
 16 THRU 20    1.120679E 01   1.202178E 01   2.854004E 00   4.883301E 00   1.805444E 01
 21 THRU 25    1.250439E 01   1.094653E 01   8.231934E 00   1.052856E 01   8.406982E 00
 26 THRU 30    1.106738E 01   1.056567E 01   9.001465E 00   1.517334E 00   3.979248E 00
 31 THRU 31    0.0

QRRA   0.65144E 01 QRTO   0.27465E 03 QCRA   0.34239E 02 QCTO   0.14067E 04

C1     0.59400E 01 C2     0.13960E 02 C22    0.14990E 02 C23    0.11800E 02

C24    0.13010E 02 C25    0.21510E 02 C26    0.20800E 02 C27    0.20800E 02

C28    0.20800E 02 C3     0.97000E 01 C4     0.34300E 01 C5     0.34300E 01

C6     0.42090E-01 G53    0.20100E 00 G62    0.14018E 01

* * * *
TIME  3.10000E 01 DTIMEU  5.00002E-02 CSGMIN(   14)  6.06040E-04 DTMPCC(   15)  1.53809E-02 ARLXCC(   14)  3.90625E-03

  1 THRU  5    1.160718E 01   1.103564E 01   1.262329E 01   1.025342E 01   1.083545E 01
  6 THRU 10    5.645313E 01   7.445068E 00   6.777100E 00   8.811768E 00   9.389404E 00
 11 THRU 15    1.024072E 01   1.082422E 01   5.647607E 01   1.078711E 01   1.078833E 01
 16 THRU 20    1.094458E 01   1.255518E 01   2.795410E 00   4.787109E 00   1.805103E 01
 21 THRU 25    1.225049E 01   1.069189E 01   8.065406E 00   1.025952E 01   8.227539E 00
 26 THRU 30    1.079834E 01   1.030664E 01   8.798340E 00   1.486328E 00   3.897949E 00
 31 THRU 31    0.0

QRRA   0.63869E 01 QRTO   0.28109E 03 QCRA   0.33632E 02 QCTO   0.14406E 04

C1     0.59400E 01 C2     0.13960E 02 C22    0.14990E 02 C23    0.11980E 02
```

C28	0.20800E 02 C3	0.97000E 01 C4	0.34300F 01 C5	0.34300E 01	
C6	0.42090F-01 G53	0.20100E 00 G62	0.15751E 01		

* * * *

TIME 4.00000F 01 OTIMEU 5.00002E-02 CSGMIN(14) 6.05606E-04 DTMPCC(14) 1.66016F-02 ARLXCC(14) 1.95313E-03

1 THRU 5	9.546631E 00	8.908447E 00	1.030005E 01	8.429688F 00	8.807129E 00
6 THRU 10	5.636816F 01	6.138184E 00	5.634766E 00	7.238525E 00	7.686279E 00
11 THRU 15	8.420898E 00	8.799072E 00	5.639258F 01	8.814697E 00	8.816895E 00
16 THRU 20	8.823730E 00	1.025415E 01	2.295654E 00	3.937012E 00	1.802393E 01
21 THRU 25	1.004517E 01	8.635010E 00	6.653564E 00	8.183838E 00	6.744141E 00
26 THRU 30	8.618164E 00	8.239014E 00	7.157471E 00	1.216553E 00	3.196777E 00
31 THRU 31	9.0				

QRRA	0.53033E 01 QRTD	0.33354E 03 QCRA	0.28440E 02 QCTD	0.17193E 04
C1	0.59400E 01 C2	0.13960E 02 C22	0.14990E 02 C23	0.11880E 02
C24	0.13010E 02 C25	0.21510E 02 C26	0.20800E 02 C27	0.20800E 02
C28	0.20800E 02 C3	0.97000E 01 C4	0.34300E 01 C5	0.34300E 01
C6	0.42090E-01 G53	0.20100E 00 G62	0.15926E 01	

B-23

* * * *

TIME 4.10000E 01 OTIMEU 5.00002E-02 CSGMIN(14) 6.05560E-04 DTMPCC(15) 1.44043E-02 ARLXCC(14) 2.19727E-03

1 THRU 5	9.333740E 00	8.695801E 00	1.005396F 01	8.245361E 00	8.600586E 00

```
TRANSIENT WATER/KHF2/ETHANOL FUSIBLE HEAT SINK
  6  THRU  10    5.629150E 01   4.138428E 00   4.169189E 00   5.561279E 00   6.099121E 00
 11  THRU  15    6.780273E 00   6.950928E 00   5.631689E 01   7.050293E 00   7.049805E 00
 16  THRU  20    6.912842E 00   8.198730E 00   1.764404E 00   3.170898E 00   1.800024E 01
 21  THRU  25    8.042969E 00   6.747559E 00   4.923828E 00   6.234863E 00   4.810303E 00
 26  THRU  30    6.730225E 00   6.350830E 00   4.793213E 00   9.660645E-01   2.560547E 00
 31  THRU  31    0.0

QRRA   0.39001E 01 QRTO   0.37517E 03 QCRA   0.21856E 02 QCTO   0.19466E 04

C1     0.59400E 01 C2     0.13960E 02 C22    0.14990E 02 C23    0.54292E 00

C24    0.13010E 02 C25    0.98301E 00 C26    0.20800E 02 C27    0.20800E 02

C28    0.95056E 00 C3     0.97000E 01 C4     0.34300E 01 C5     0.34300E 01

C6     0.42090E-01 G53    0.20100E 00 G62    0.17350E 01

 *  *  *  *
TIME  5.00000E 01 DTIMEU  5.00002E-02 CSGMIN(  14)  6.05164E-04 DTMPCC(  27)  1.14502E-01 ARLXCC(  14)  1.29395E-02

  1  THRU   5    7.435303E 00   6.833984E 00   8.012207E 00   6.601074E 00   6.753906E 00
  6  THRU  10    5.628345E 01   3.895752E 00   3.8?8652E 00   5.158691E 00   5.896973E 00
 11  THRU  15    6.593994E 00   6.745361E 00   5.?30859E 01   6.852783E 00   6.851074E 00
 16  THRU  20    6.483643E 00   7.981445E 00   1.642578E 00   3.083740E 00   1.799756E 01
 21  THRU  25    7.830811E 00   6.537842E 00   4.660400E 00   4.952637E 00   4.317627E 00
 26  THRU  30    6.515381E 00   5.512939E 00   4.506592E 00   9.343262E-01   2.492920E 00
 31  THRU  31    0.0

QRRA   0.36321E 01 QRTO   0.37896E 03 QCRA   0.20620E 02 QCTO   0.19679E 04

C1     0.59400E 01 C2     0.13960E 02 C22    0.14990E 02 C23    0.54292E 00

C24    0.59456E 00 C25    0.98301E 00 C26    0.20800E 02 C27    0.95056E 00

C28    0.95056E 00 C3     0.97000E 01 C4     0.34300E 01 C5     0.34300E 01

C6     0.42090E-01 G53    0.20100E 00 G62    0.17350E 01

 *  *  *  *
TIME  5.10000E 01 DTIMEU  5.00002E-02 CSGMIN(  14)  6.05117E-04 DTMPCC(  28)  1.75781E-02 ARLXCC(  20)  1.46484E-03

  1  THRU   5    7.201416E 00   6.615723E 00   7.791016E 00   6.414551E 00   6.514404E 00
  6  THRU  10    5.626597E 01   3.334229E 00   3.553223E 00   4.857422E 00   5.670898E 00
 11  THRU  15    6.406982E 00   6.505615E 00   5.629126E 01   6.632568E 00   6.636230E 00
 16  THRU  20    6.157715E 00   7.760742E 00   1.543701E 00   2.996826E 00   1.799170E 01
 21  THRU  25    7.611328E 00   6.299561E 00   4.348877E 00   4.510010E 00   3.935059E 00
 26  THRU  30    6.213623E 00   4.729248E 00   3.849854E 00   8.986816E-01   2.422607E 00
 31  THRU  31    0.0

QRRA   0.33211E 01 QRTO   0.38240E 03 QCRA   0.19195E 02 QCTO   0.19877E 04

C1     0.59400E 01 C2     0.13960E 02 C22    0.14990E 02 C23    0.54292E 00
```

B-24

WARMUP MODEL

WARMUP CASE QHX = 1500 BTU/HR

```
BCD 3THERMAL LPCS
BCD 9 TRANSIENT WATER/KHF2/ETHANOL FUSIBLE HEAT SINK
BCD 9 WARM-UP CASE FUSIBLE HEAT SINK
END
BCD 3NODE DATA
CGS 1,50.,A1,5.94          $ LIQUID AROUND PUMP
CGS 2,50.,A1,13.96         $ LIQUID AROUND PUMP
CGS 3,50.,A1,9.7           $ LIQUID BELOW BATTERY
CGS 4,50.,A1,3.43          $ LIQUID AROUND BLADDER
CGS 5,50.,A1,3.43          $ LIQUID AROUND BLADDER
    6,50.,.168             $ INSULATION AROUND SIDE OF MOTOR SECTION
    7,50.,.0212            $ METAL S/S BOTTOM BELOW MOTOR
    8,50.,.171             $ METAL S/S SIDE MOTOR SECTION
    9,50.,.036             $ METAL S/S  TOP MOTOR SECTION
    10,50.,.059            $ METAL S/S TOP BATTERY SECTION
    11,50.,.067            $ METAL S/S OUTER SIDE BATTERY SECTION
    12,50.,.067            $ METAL S/S INNER SIDE BATTERY SECTION
    13,50.,.0159           $ INSULATION AT BOTTOM OF MOTOR SECTION
    14,50.,.0666           $ METAL S/S AROUND BATTERY
    15,50.,.528            $ BATTERY
    16,50.,.159            $ PUMP/MOTOR
    17,50.,.0127           $ METAL S/S BOTTOM OF BATTERY
    18,50.,.0159           $ INSULATION ATOP MOTOR SECTION
    19,50.,.0601           $ INSULATION SIDE OF BATTERY SECTION
    20,50.,.0322           $ FLUID IN PUMP 1 IN3
    21,50.,.0127           $ METAL BOTTOM OF BATTERY SECTION
CGS 22,50.,A1,14.99        $ LIQUID AROUND PUMP
CGS 23,50.,A1,11.88        $ LIQUID AROUND PUMP
CGS 24,50.,A1,13.01        $ LIQUID AROUND PUMP
CGS 25,50.,A1,21.51        $ LIQUID AROUND PUMP
CGS 26,50.,A1,20.8         $ LIQUID BELOW PUMP
CGS 27,50.,A1,20.8         $ LIQUID BELOW PUMP
CGS 28,50.,A1,20.8         $ LIQUID BELOW PUMP
    29,50.,.0114           $ INSULATION ATOP BATTERY SECTION
    30,50.,.0114         $ INSULATION ON BOTTOM OF BATTERY SECTION
    31,50.,.161            $ FLUID IN OUTSIDE CIRC LOOP 5 IN3
    -100,70.,1.            $ ENVIRONMENT
END

RELATIVE NODE NUMBERS                        ACTUAL NODE NUMBERS

   1  THRU   10        1     2     3     4     5     6     7     8     9    10
  11  THRU   20       11    12    13    14    15    16    17    18    19    20
  21  THRU   30       21    22    23    24    25    26    27    28    29    30
  31  THRU   32       31   100
BCD 3CONDUCTOR DATA
REM NOTE CGS CONDUCTOR CONSTANT VALUES FOR K=.375BTU-FT/HR-FT2-F
REM K=1.3 BTU-FT/HR-FT2-F AT 6.2F
REM K= .375 BTU-FT/HR-FT2-F AT 18.8F
CGS 10,3,12,A8,.184
CGS 11,3,17,A8,.604
CGS 13,3,11,A8,.184
CGS 14,3,21,A8,.604
CGS 15,4,11,A8,26.2
CGS 16,4,5,A8,9.5E-3
CGS 17,4,14,A8,.0931
CGS 18,5,12,A8,26.2
CGS 19,5,14,A8,.0931
```

```
       22,7,21,.022
       23,7,8,.0456
       24,8,9,.0552
       26,9,18,.0697
       27,9,16,2.35E-3     $ CONDUCTANCE THRU PTFCE PLASTIC
       28,9,10,.0363
       29,10,11,.0285
       30,10,14,.0533
       31,10,12,.0285
       32,11,19,.467
       33,11,12,.994
       35,11,21,.0155
       39,14,17,.0533
       40,14,15,109.1
       41,21,12,.0155
   REM CONDUCTANCES FOR CONVECTION AT 1G
       42,100,13,.145      $ NATL CONV TO IN5
       43,100,30,.0872
       44,100,6,1.174      $ NATL CONV TO IN5
       45,100,19,.515
       46,100,29,.0872
       47,100,18,.145
   REM END CONDUCTANCES FOR 1G EXTERNAL CONVECTION
   CGS 49,1,2,A8,.035
   CGS 50,1,24,A8,.014
   CGS 51,1,25,A8,.014
   CGS 52,1,9,A8,.0151
   CGS 53,1,8,A8,1.467
   CGS 54,1,26,A8,.0122
   CGS 55,1,16,A9,.0899   $ CONDUCTANCE FLUID AROUND PUMP TO PUMP
   CGS 56,2,22,A8,.11
   CGS 57,2,16,A10,.0539  $ CONDUCTANCE FLUID AROUND PUMP TO PUMP
   CGS 58,2,12,A8,.428
   CGS 59,2,26,A8,.0288
   CGS 60,2,9,A8,.0355
   CGS 61,2,8,A8,.24
   CGS 62,22,23,A8,.5
   CGS 63,22,24,A8,.064
   CGS 64,22,26,A8,.0309
   CGS 65,22,12,A8,.425
   CGS 66,22,16,A11,.095  $ CONDUCTANCE FLUID AROUND PUMP TO PUMP
   CGS 67,22,9,A8,.0382
   CGS 68,23,12,A8,.1066
   CGS 69,23,26,A8,.0245
   CGS 70,23,25,A8,.067
   CGS 71,23,6,A8,1.6
   CGS 72,23,9,A8,.0302
   CGS 73,24,16,A12,.1163 $ CONDUCTANCE FLUID AROUND PUMP TO PUMP
   CGS 74,24,25,A8,.6
   CGS 75,24,9,A8,.0331
   CGS 76,24,26,A8,.0268
   CGS 77,25,8,A8,1.67
   CGS 78,25,26,A8,.0443
   CGS 79,25,9,A8,.0547
   CGS 80,26,27,A8,.466
   CGS 81,26,16,A8,.0548
   CGS 82,26,12,A8,.0325
   CGS 83,26,8,A8,.37
   CGS 84,27,28,A8,.466
   CGS 85,27,8,A8,.37
   CGS 86,27,12,A8,.0325
```

```
CGS 87,28,7,A8,.932
CGS 88,28,8,A8,.37
CGS 89,28,12,A8,.0325
    90,18,29,7.41E-4
    91,29,10,.01645
    92,19,29,8.75E-4
    93,30,21,.0419
    94,30,19,8.75E-4
REM ONE WAY CONDUCTORS
    110,-20,31,-31,3,-3,28,-28,27,-27,26,192.
    111,-26,2,-2,1,-1,25,-25,23,-23,22,-22,24,-24,20,192.
    116,16,20,3.27        $ CONDUCTANCE PUMP TO PUMPED FLUID
    117,6,13,1.59E-3      $ CONDUCTANCE IN INSULATION
    118,6,18,1.59E-3      $ CONDUCTANCE IN INSULATION
    119,6,19,1.92E-3      $ CONDUCTANCE IN INSULATION
    120,13,30,7.41E-4     $ CONDUCTANCE IN INSULATION
    121,6,8,.563          $ INS TO CAN
    122,7,13,.0696           $ INS TO CAN
REM RADIATION CONDUCTORS
    -100,4,14,2.05E-10
    -101,5,14,2.05E-10
    -102,100,13,.124E-10 $ INSULATION E= .05
    -103,100,30,.0747E-10    $ INSULATION E=.05
    -104,100,6,1.0E-10   $ INSULATION E= .05
    -105,100,19,.441E-10     $ INSULATION E=.05
    -106,100,29,.0747E-10    $ INSULATION E=.05
    -107,100,18,.124E-10     $ INSULATION E=.05
END
```

FLOW CONDUCTORS, 192. BTU/HR-°F

RELATIVE CONDUCTOR NUMBERS	ACTUAL CONDUCTOR NUMBERS									
1 THRU 10	10	11	13	14	15	16	17	18	19	22
11 THRU 20	23	24	26	27	28	29	30	31	32	33
21 THRU 30	35	39	40	41	42	43	44	45	46	47
31 THRU 40	49	50	51	52	53	54	55	56	57	58
41 THRU 50	59	60	61	62	63	64	65	66	67	68
51 THRU 60	69	70	71	72	73	74	75	76	77	78
61 THRU 70	79	80	81	82	83	84	85	86	87	88
71 THRU 80	89	90	91	92	93	94	110	111	116	117
81 THRU 90	118	119	120	121	122	100	101	102	103	104
91 THRU 93	105	106	107							

```
BCD 3CONSTANTS DATA
     TIMEND,3.,OUTPUT,.25
     OTIMEI,.01
     NLOOP,3000
     DRLXCA,.05,ARLXCA,.05
END
BCD 3ARRAY DATA
     1,-50.,.0457,6.19,.0457,6.20,1.0,18.79,1.0,18.8,.0457
     100.,.0457,END
     -4,C1,C2,C22,C23,END
     -5,C24,C25,C26,C27,END
     -6,C28,C3,C4,C5,END
     -7,C6,G53,G62,END
REM NOTE CHANGE IN ARRAY DATA 8 THRU 12
     8,-50.,3.47,6.20,3.47,18.80,1.0,100.,1.0,END
     9,-50.,1.36,6.200,1.36,18.80,1.0,100.,1.0,END
     10,-50.,2.03,6.200,2.03,18.80,1.0,100.,1.0,END
     11,-50.,1.78,6.200,1.78,18.80,1.0,100.,1.0,END
     12,-50.,1.60,6.200,1.60,18.80,1.0,100.,1.0,END
END
```

```
 BCO 3EXECUTION
DIMENSION X(20G)                                                    F
NDIM=200                                                            F
NTH=0                                                               F
 REM SET T(I) TO 6.2F
OD 10 I=1,31                                                        F
T(I)=T(I)-43.8                                                      F
10  CONTINUE                                                        F
      CSGDMP
      CNFWBK
  END
  BCO 3VARIABLES 1
      VARCSM(T     1,C     1,A1,5.94)
      VARCSM(T     2,C     2,A1,13.96)
      VARCSM(T     3,C     3,A1,9.7)
      VARCSM(T     4,C     4,A1,3.43)
      VARCSM(T     5,C     5,A1,3.43)
      VARCSM(T    22,C    22,A1,14.99)
      VARCSM(T    23,C    23,A1,11.88)
      VARCSM(T    24,C    24,A1,13.01)
      VARCSM(T    25,C    25,A1,21.51)
      VARCSM(T    26,C    26,A1,20.8)
      VARCSM(T    27,C    27,A1,20.8)
      VARCSM(T    28,C    28,A1,20.8)
      VARGSM(G    10,T     3,T    12,A8,.184)
      VARGSM(G    11,T     3,T    17,A8,.604)
      VARGSM(G    13,T     3,T    11,A8,.184)
      VARGSM(G    14,T     3,T    21,A8,.604)
      VARGSM(G    15,T     4,T    11,A8,26.2)
      VARGSM(G    16,T     4,T     5,A8,9.5E-3)
      VARGSM(G    17,T     4,T    14,A8,.0931)
      VARGSM(G    18,T     5,T    12,A8,26.2)
      VARGSM(G    19,T     5,T    14,A8,.0931)
      VARGSM(G    49,T     1,T     2,A8,.035)
      VARGSM(G    50,T     1,T    24,A8,.014)
      VARGSM(G    51,T     1,T    25,A8,.014)
      VARGSM(G    52,T     1,T     9,A8,.0151)
      VARGSM(G    53,T     1,T     8,A8,1.467)
      VARGSM(G    54,T     1,T    26,A8,.0122)
      VARGSM(G    55,T     1,T    16,A9,.0899)
      VARGSM(G    56,T     2,T    22,A8,.11)
      VARGSM(G    57,T     2,T    16,A10,.0539)
      VARGSM(G    58,T     2,T    12,A8,.428)
      VARGSM(G    59,T     2,T    26,A8,.0288)
      VARGSM(G    60,T     2,T     9,A8,.0355)
      VARGSM(G    61,T     2,T     8,A8,.24)
      VARGSM(G    52,T    22,T    23,A8,.5)
      VARGSM(G    63,T    22,T    24,A8,.064)
      VARGSM(G    64,T    22,T    26,A8,.0309)
      VARGSM(G    65,T    22,T    12,A8,.425)
      VARGSM(G    66,T    22,T    16,A11,.095)
      VARGSM(G    57,T    22,T     9,A8,.0382)
      VARGSM(G    68,T    23,T    12,A8,.1066)
      VARGSM(G    69,T    23,T    26,A8,.0245)
      VARGSM(G    70,T    23,T    25,A8,.067)
      VARGSM(G    71,T    23,T     8,A8,1.6)
      VARGSM(G    72,T    23,T     9,A8,.0302)
      VARGSM(G    73,T    24,T    16,A12,.1163)
      VARGSM(G    74,T    24,T    25,A8,.6)
      VARGSM(G    75,T    24,T     9,A8,.0331)
      VARGSM(G    76,T    24,T    26,A8,.0268)
```

FORTRAN STATEMENTS TO SET INITIAL TEMPERATURE TO 6.2°F

```
      VARGSM(G    77,T    25,T     8,A8,1.67)
      VARGSM(G    78,T    25,T    26,A8,.0443)
      VARGSM(G    79,T    25,T     9,A8,.0547)
      VARGSM(G    80,T    26,T    27,A8,.466)
      VARGSM(G    81,T    26,T    16,A8,.0548)
      VARGSM(G    82,T    26,T    12,A8,.0325)
      VARGSM(G    83,T    26,T     8,A8,.37)
      VARGSM(G    84,T    27,T    28,A8,.466)
      VARGSM(G    85,T    27,T     8,A8,.37)
      VARGSM(G    86,T    27,T    12,A8,.0325)
      VARGSM(G    87,T    28,T     7,A8,.932)
      VARGSM(G    88,T    28,T     8,A8,.37)
      VARGSM(G    89,T    28,T    12,A8,.0325)
ENDV1
      STFSEP(92.1,Q16)     $ MOTOR Q
      STFSEP(1500.,Q31)    $ HEAT EXCHANGER Q
END
BCD 3VARIABLES 2
END
BCD 3OUTPUT CALLS
     PRNTMP
     PRINTL(A4,C1,C2,C22,C23)
     PRINTL(A5,C24,C25,C26,C27)
     PRINTL(A6,C28,C3,C4,C5)
     PRINTL(A7,C6,G53,G62)
END
```

PUMP/MOTOR POWER DISSIPATION

POWER DISSIPATION FROM HX TO FLUID IN EXTERNAL LOOP

```
TRANSIENT WATER/KHF2/ETHANOL FUSIBLE HEAT SINK        WARM-UP CASE FUSIBLE HEAT SINK

* * * *
TIME  0.0         DTIMEU  0.0          CSGMIN(    0)    0.0         DTMPCC(     0)    0.0          ARLXCC(    0)    0.0

      1 THRU    5      6.200012E 00       6.200012E 00       6.200012E 00       6.200012E 00       6.200012E 00
      6 THRU   10      6.200012E 00       6.200012E 00       6.200012E 00       6.200012E 00       6.200012E 00
     11 THRU   15      6.200012E 00       6.200012E 00       6.200012E 00       6.200012E 00       6.200012E 00
     16 THRU   20      6.200012E 00       6.200012E 00       6.200012E 00       6.200012E 00       6.200012E 00
     21 THRU   25      6.200012E 00       6.200012E 00       6.200012E 00       6.200012E 00       6.200012E 00
     26 THRU   30      6.200012E 00       6.200012E 00       6.200012E 00       6.200012E 00       6.200012E 00
     31 THRU   32      6.200012E 00       7.000000E 01

C1     0.59400E 01 C2     0.13960E 02 C22    0.14990E 02 C23    0.11880E 02

C24    0.13010E 02 C25    0.21510E 02 C26    0.20800E 02 C27    0.20800E 02

C28    0.20800E 02 C3     0.97000E 01 C4     0.34300E 01 C5     0.34300E 01

C6     0.16800E 00 G53    0.50905E 01 G62    0.17350E 01
 A  31 NODE PROBLEM USING LPCS
NODE   20 HAS THE CSGMIN OF 1.64900E-04, NODE   10 HAS THE CSGMAX OF 3.61852E-01
NODE  C-VALUE  CSG-VALUE COND TYPE G-VALUE TO NODE TYPE
   1 5.940E 00 3.007E-02
                               31  LIN 1.214E-01     2 DIFF
                               32  LIN 4.858E-02    24 DIFF
                               33  LIN 4.858E-02    25 DIFF
                               34  LIN 5.240E-02     9 DIFF
                               35  LIN 5.090E 00     8 DIFF
                               36  LIN 4.233E-02    26 DIFF
                               37  LIN 1.223E-01    16 DIFF
                               78  LIN 1.920E 02     2 DIFF, ONE WAY CONDUCTOR
   2 1.396E 01 7.153E-02
                               31  LIN 1.214E-01     1 DIFF
                               38  LIN 3.817E-01    22 DIFF
                               39  LIN 1.094E-01    16 DIFF
                               40  LIN 1.485E 00    12 DIFF
                               41  LIN 9.994E-02    26 DIFF
                               42  LIN 1.232E-01     9 DIFF
                               43  LIN 8.328E-01     8 DIFF
                               78  LIN 1.920E 02    26 DIFF, ONE WAY CONDUCTOR
   3 9.700E 00 4.912E-02
                                1  LIN 6.385E-01    12 DIFF
                                2  LIN 2.096E 00    17 DIFF
                                3  LIN 6.385E-01    11 DIFF
                                4  LIN 2.096E 00    21 DIFF
                               77  LIN 1.920E 02    31 DIFF, ONE WAY CONDUCTOR
   4 3.430E 00 3.755E-02
                                5  LIN 9.091E 01    11 DIFF
                                6  LIN 3.296E-02     5 DIFF
                                7  LIN 3.231E-01    14 DIFF
                               86  RAD 2.050E-10    14 DIFF
   5 3.430E 00 3.755E-02
                                6  LIN 3.296E-02     4 DIFF
                                8  LIN 9.091E 01    12 DIFF
                                9  LIN 3.231E-01    14 DIFF
```

```
   TRANSIENT WATER/KHF2/ETHANOL FUSIBLE HEAT SINK        WARM-UP CASE FUSIBLE HEAT SINK
                              87  RAD 2.050E-10   14 DIFF
 6 1.680E-01 9.376E-02
                              27  LIN 1.174E 00   32 BOUN
                              80  LIN 1.590E-03   13 DIFF
                              81  LIN 1.590E-03   18 DIFF
                              82  LIN 1.920E-03   19 DIFF
                              84  LIN 5.630E-01    8 DIFF
                              90  RAD 1.000E-10   32 BOUN
 7 2.120E-02 6.288E-03
                              10  LIN 2.200E-02   21 DIFF
                              11  LIN 4.560E-02    8 DIFF
                              69  LIN 3.234E 00   28 DIFF
                              85  LIN 6.960E-02   13 DIFF
 8 1.710E-01 7.849E-03
                              11  LIN 4.560E-02    7 DIFF
                              12  LIN 5.520E-02    9 DIFF
                              35  LIN 5.090E 00    1 DIFF
                              43  LIN 8.328E-01    2 DIFF
                              53  LIN 5.552E 00   23 DIFF
                              59  LIN 5.795E 00   25 DIFF
                              65  LIN 1.284E 00   26 DIFF
                              67  LIN 1.284E 00   27 DIFF
                              70  LIN 1.284E 00   28 DIFF
                              84  LIN 5.630E-01    6 DIFF
 9 3.600E-02 4.086E-02
                              12  LIN 5.520E-02    8 DIFF
                              13  LIN 6.970E-02   18 DIFF
                              14  LIN 2.350E-03   16 DIFF
                              15  LIN 3.630E-02   10 DIFF
                              34  LIN 5.240E-02    1 DIFF
                              42  LIN 1.232E-01    2 DIFF
                              49  LIN 1.326E-01   22 DIFF
                              54  LIN 1.048E-01   23 DIFF
                              57  LIN 1.149E-01   24 DIFF
                              61  LIN 1.898E-01   25 DIFF
10 5.900E-02 3.619E-01
                              15  LIN 3.630E-02    9 DIFF
                              16  LIN 2.850E-02   11 DIFF
                              17  LIN 5.330E-02   14 DIFF
                              18  LIN 2.850E-02   12 DIFF
                              73  LIN 1.645E-02   29 DIFF
11 6.700E-02 7.200E-04
                               3  LIN 6.385E-01    3 DIFF
                               5  LIN 9.091E 01    4 DIFF
                              16  LIN 2.850E-02   10 DIFF
                              19  LIN 4.670E-01   19 DIFF
                              20  LIN 9.940E-01   12 DIFF
                              21  LIN 1.550E-02   21 DIFF
12 6.700E-02 6.960E-04
                               1  LIN 6.385E-01    3 DIFF
```

```
                                 8  LIN 9.091E 01    5 DIFF
                                18  LIN 2.850E-02   10 DIFF
                                20  LIN 9.940E-01   11 DIFF
                                24  LIN 1.550E-02   21 DIFF
                                40  LIN 1.485E 00    2 DIFF
                                47  LIN 1.475E 00   22 DIFF
                                50  LIN 3.699E-01   23 DIFF
                                64  LIN 1.128E-01   25 DIFF
                                68  LIN 1.128E-01   27 DIFF
                                71  LIN 1.128E-01   28 DIFF
 13 1.590E-02 7.127E-02
                                25  LIN 1.450E-01   32 BOUN
                                80  LIN 1.590E-03    6 DIFF
                                83  LIN 7.410E-04   30 DIFF
                                85  LIN 6.960E-02    7 DIFF
                                88  RAD 1.240E-11   32 BOUN
 14 6.660E-02 6.054E-04
                                 7  LIN 3.231E-01    4 DIFF
                                 9  LIN 3.231E-01    5 DIFF
                                17  LIN 5.330E-02   10 DIFF
                                22  LIN 5.330E-02   17 DIFF
                                23  LIN 1.091E 02   15 DIFF
                                86  RAD 2.050E-10    4 DIFF
                                87  RAD 2.050E-10    5 DIFF
 15 5.280E-01 4.840E-03
                                23  LIN 1.091E 02   14 DIFF
 16 1.590E-01 3.927E-02
                                14  LIN 2.350E-03    9 DIFF
                                37  LIN 1.223E-01    1 DIFF
                                39  LIN 1.094E-01    2 DIFF
                                48  LIN 1.691E-01   22 DIFF
                                55  LIN 1.861E-01   24 DIFF
                                63  LIN 1.902E-01   26 DIFF
                                79  LIN 3.270E 00   20 DIFF
 17 1.270E-02 5.909E-03
                                 2  LIN 2.096E 00    3 DIFF
                                22  LIN 5.330E-02   14 DIFF
 18 1.590E-02 7.124E-02
                                13  LIN 6.970E-02    9 DIFF
                                30  LIN 1.450E-01   32 BOUN
                                72  LIN 7.410E-04   29 DIFF
                                81  LIN 1.590E-03    6 DIFF
                                93  RAD 1.240E-11   32 BOUN
 19 6.010E-02 5.965E-02
                                19  LIN 4.670E-01   11 DIFF
                                28  LIN 5.150E-01   32 BOUN
                                74  LIN 8.750E-04   29 DIFF
                                76  LIN 8.750E-04   30 DIFF
                                82  LIN 1.920E-03    6 DIFF
```

```
TRANSIENT WATER/KHF2/ETHANOL FUSIBLE HEAT SINK        WARM-UP CASE FUSIBLE HEAT SINK
                        91  RAD 4.410E-11    32 BOUN
20 3.220E-02 1.649E-04
                        78  LIN 1.920E 02    24 DIFF, ONE WAY CONDUCTOR
                        79  LIN 3.270E 00    16 DIFF
21 1.270E-02 5.797E-03
                         4  LIN 2.096E 00     3 DIFF
                        10  LIN 2.200E-02     7 DIFF
                        21  LIN 1.550E-02    11 DIFF
                        24  LIN 1.550E-02    12 DIFF
                        75  LIN 4.190E-02    30 DIFF
22 1.499E 01 7.639E-02
                        38  LIN 3.817E-01     2 DIFF
                        44  LIN 1.735E 00    23 DIFF
                        45  LIN 2.221E-01    24 DIFF
                        46  LIN 1.072E-01    26 DIFF
                        47  LIN 1.475E 00    12 DIFF
                        48  LIN 1.691E-01    16 DIFF
                        49  LIN 1.326E-01     9 DIFF
                        78  LIN 1.920E 02    23 DIFF, ONE WAY CONDUCTOR
23 1.188E 01 5.938E-02
                        44  LIN 1.735E 00    22 DIFF
                        50  LIN 3.699E-01    12 DIFF
                        51  LIN 8.501E-02    26 DIFF
                        52  LIN 2.325E-01    25 DIFF
                        53  LIN 5.552E 00     8 DIFF
                        54  LIN 1.048E-01     9 DIFF
                        78  LIN 1.920E 02    25 DIFF, ONE WAY CONDUCTOR
24 1.301E 01 6.680E-02
                        32  LIN 4.858E-02     1 DIFF
                        45  LIN 2.221E-01    22 DIFF
                        55  LIN 1.861E-01    16 DIFF
                        56  LIN 2.082E 00    25 DIFF
                        57  LIN 1.149E-01     9 DIFF
                        58  LIN 9.300E-02    26 DIFF
                        78  LIN 1.920E 02    22 DIFF, ONE WAY CONDUCTOR
25 2.151E 01 1.073E-01
                        33  LIN 4.858E-02     1 DIFF
                        52  LIN 2.325E-01    23 DIFF
                        56  LIN 2.082E 00    24 DIFF
                        59  LIN 5.795E 00     8 DIFF
                        60  LIN 1.537E-01    26 DIFF
                        61  LIN 1.898E-01     9 DIFF
                        78  LIN 1.920E 02     1 DIFF, ONE WAY CONDUCTOR
26 2.080E 01 1.062E-01
                        36  LIN 4.233E-02     1 DIFF
                        41  LIN 9.994E-02     2 DIFF
                        46  LIN 1.072E-01    22 DIFF
                        51  LIN 8.501E-02    23 DIFF
                        58  LIN 9.300E-02    24 DIFF
```

TRANSIENT WATER/KHF2/ETHANOL FUSIBLE HEAT SINK WARM-UP CASE FUSIBLE HEAT SINK

```
                        60  LIN 1.537E-01   25 DIFF
                        62  LIN 1.617E 00   27 DIFF
                        63  LIN 1.902E-01   16 DIFF
                        64  LIN 1.128E-01   12 DIFF
                        65  LIN 1.284E 00    8 DIFF
                        77  LIN 1.920E 02   27 DIFF, ONE WAY CONDUCTOR
 27 2.080E 01 1.058E-01
                        62  LIN 1.617E 00   26 DIFF
                        66  LIN 1.617E 00   28 DIFF
                        67  LIN 1.284E 00    8 DIFF
                        68  LIN 1.128E-01   12 DIFF
                        77  LIN 1.920E 02   28 DIFF, ONE WAY CONDUCTOR
 28 2.080E 01 1.049E-01
                        66  LIN 1.617E 00   27 DIFF
                        69  LIN 3.234E 00    7 DIFF
                        70  LIN 1.284E 00    8 DIFF
                        71  LIN 1.128E-01   12 DIFF
                        77  LIN 1.920E 02    3 DIFF, ONE WAY CONDUCTOR
 29 1.140E-02 1.046E-01
                        29  LIN 8.720E-02   32 BOUN
                        72  LIN 7.410E-04   18 DIFF
                        73  LIN 1.645E-02   10 DIFF
                        74  LIN 8.750E-04   19 DIFF
                        92  RAD 7.470E-12   32 BOUN
 30 1.140E-02 8.481E-02
                        26  LIN 8.720E-02   32 BOUN
                        75  LIN 4.190E-02   21 DIFF
                        76  LIN 8.750E-04   19 DIFF
                        83  LIN 7.410E-04   13 DIFF
                        89  RAD 7.470E-12   32 BOUN
 31 1.610E-01 8.385E-04
                        77  LIN 1.920E 02   20 DIFF, ONE WAY CONDUCTOR

* * * *
TIME 0.0        DTIMEU 0.0        CSGMIN(    0)  0.0        DTMPCC(    0)  0.0        ARLXCC(    0)  0.0

   1 THRU  5    6.200012E 00   6.200012E 00   6.200012E 00   6.200012E 00   6.200012E 00
   6 THRU 10    6.200012E 00   6.200012E 00   6.200012E 00   6.200012E 00   6.200012E 00
  11 THRU 15    6.200012E 00   6.200012E 00   6.200012E 00   6.200012E 00   6.200012E 00
  16 THRU 20    6.200012E 00   6.200012E 00   6.200012E 00   6.200012E 00   6.200012E 00
  21 THRU 25    6.200012E 00   6.200012E 00   6.200012E 00   6.200012E 00   6.200012E 00
  26 THRU 30    6.200012E 00   6.200012E 00   6.200012E 00   6.200012E 00   6.200012E 00
  31 THRU 32    6.200012E 00   7.000000E 01

C1    0.59400E 01 C2    0.13960E 02 C22   0.14990E 02 C23   0.11880E 02
C24   0.13010E 02 C25   0.21510E 02 C26   0.20800E 02 C27   0.20800E 02
C28   0.20800E 02 C3    0.97000E 01 C4    0.34300E 01 C5    0.34300E 01
C6    0.16800E 00 G53   0.50905E 01 G62   0.17350E 01

* * * *
TIME  2.50000E-01 DTIMEU  5.00011E-03 CSGMIN(   20)  1.64899E-04 DTMPCC(   29)  2.50732E-01 ARLXCC(    7)  9.76563E-04
```

1	THRU	5	7.135742E 00	7.461426E 00	1.435132F 01	7.221436E 00	6.493896E 00

```
TRANSIENT WATER/KHF2/ETHANOL FUSIBLE HEAT SINK          WARM-UP CASE FUSIBLE HEAT SINK
 6  THRU  10     4.737402E 01     1.386499E 01     8.430176E 00     1.025220E 01     8.336426E 00
11  THRU  15     7.427490E 00     6.568359E 00     5.043311E 01     6.399414E 00     6.393555E 00
16  THRU  20     3.155493E 01     1.397974E 01     4.957910E 01     4.031274E 01     5.670410E 00
21  THRU  25     1.538477E 01     6.295654E 00     6.413818E 00     6.247314E 00     6.571289E 00
26  THRU  30     8.500732E 00     1.053735E 01     1.284277E 01     5.526538E 01     5.000537E 01
31  THRU  32     1.448169E 01     7.000000E 01

C1      0.59400E 01 C2      0.13960E 02 C22     0.14990E 02 C23     0.11880E 02
C24     0.13010E 02 C25     0.21510E 02 C26     0.20800E 02 C27     0.20800E 02
C28     0.20800E 02 C3      0.97000E 01 C4      0.34300E 01 C5      0.34300E 01
C6      0.16800E 00 G53     0.46502E 01 G62     0.17210E 01

*  *  *  *
TIME  5.00000E-01 DTIMEU  5.00011E-03 CSGMIN(   20)   1.64899E-04 OTMPCC(   25)   7.29980E-02 ARLXCC(    7)   1.22070E-03

 1  THRU   5     1.103760E 01     1.148169E 01     1.511035E 01     8.424072E 00     7.181641E 00
 6  THRU  10     5.105908E 01     1.597534E 01     1.162573E 01     1.304248E 01     1.080029E 01
11  THRU  15     8.635010E 00     7.328613E 00     5.281885E 01     6.847168E 00     6.836182E 00
16  THRU  20     3.256641E 01     1.465576E 01     5.179102E 01     4.141040E 01     7.666260E 00
21  THRU  25     1.632300E 01     7.787598E 00     8.637451E 00     7.243896E 00     9.426025E 00
26  THRU  30     1.252539E 01     1.375464E 01     1.455444E 01     6.015845E 01     5.279199E 01
31  THRU  32     1.547119E 01     7.000000E 01

C1      0.59400E 01 C2      0.13960E 02 C22     0.14990E 02 C23     0.11880E 02
C24     0.13010E 02 C25     0.21510E 02 C26     0.20800E 02 C27     0.20800E 02
C28     0.20800E 02 C3      0.97000E 01 C4      0.34300E 01 C5      0.34300E 01
C6      0.16800E 00 G53     0.36356E 01 G62     0.15438E 01

*  *  *  *
TIME  7.50000E-01 DTIMEU  5.00011E-03 CSGMIN(   20)   1.64898E-04 OTMPCC(   21)   7.29980E-02 ARLXCC(   14)   1.46484E-03

 1  THRU   5     1.380005E 01     1.404663E 01     1.767212E 01     9.568848E 00     8.237305E 00
 6  THRU  10     5.230518E 01     1.821899E 01     1.489722E 01     1.670972E 01     1.277979E 01
11  THRU  15     9.794434E 00     8.443359E 00     5.348804E 01     7.491455E 00     7.476318E 00
16  THRU  20     3.520923E 01     1.686963E 01     5.293726E 01     4.196387E 01     1.054224E 01
21  THRU  25     1.908936E 01     1.096802E 01     1.196069E 01     1.012427E 01     1.264990E 01
26  THRU  30     1.468262E 01     1.555298E 01     1.651147E 01     6.090186E 01     5.358691E 01
31  THRU  32     1.834302E 01     7.000000E 01

C1      0.59400E 01 C2      0.13960E 02 C22     0.14990E 02 C23     0.11880E 02
C24     0.13010E 02 C25     0.21510E 02 C26     0.20800E 02 C27     0.20800E 02
C28     0.20800E 02 C3      0.97000E 01 C4      0.34300E 01 C5      0.34300E 01
C6      0.16799E 00 G53     0.27614E 01 G62     0.12250E 01

*  *  *  *
```

```
TIME  1.00000E 00 OTIMEU  5.00011E-03 CSGMIN(   20)   1.64897E-04 DTMPCC(   27)   5.18799E-01 ARLXCC(   26)   7.56836E-03

     1  THRU    5      1.602417E 01      1.635156E 01      2.116870E 01      1.070190E 01      9.463867E 00
     6  THRU   10      5.325073E 01      2.293481E 01      1.785547E 01      2.030908E 01      1.452808E 01
    11  THRU   15      1.094556E 01      9.704834E 00      5.472412E 01      8.313232E 00      8.294922E 00
    16  THRU   20      3.813721E 01      1.993555E 01      5.407324E 01      4.250220E 01      1.342236E 01
    21  THRU   25      2.257104E 01      1.367432E 01      1.443823E 01      1.300366E 01      1.498584E 01
    26  THRU   30      1.738501E 01      2.081738E 01      2.111401E 01      6.122681E 01      5.468652E 01
    31  THRU   32      2.122656E 01      7.000000E 01

C1      0.59400E 01 C2      0.13960E 02 C22     0.14990E 02 C23     0.11880E 02

C24     0.13010E 02 C25     0.21510E 02 C26     0.20800E 02 C27     0.95056E 00

C28     0.95056E 00 C3      0.44329E 00 C4      0.34300E 01 C5      0.34300E 01

C6      0.16799E 00 G53     0.20213E 01 G62     0.96961E 00

*  *  *  *
TIME  1.25000E 00 OTIMEU  5.00011E-03 CSGMIN(   20)   1.64897E-04 DTMPCC(   22)   7.90771E-01 ARLXCC(   21)   4.71191E-02

     1  THRU    5      2.416357E 01      2.417188E 01      2.507251E 01      1.181250E 01      1.081128E 01
```

```
TRANSIENT WATER/KHF2/ETHANOL FUSIBLE HEAT SINK         WARM-UP CASE FUSIBLE HEAT SINK
     6  THRU   10     5.508130E 01    2.619385E 01    2.591064E 01    2.576392E 01    1.625586E 01
    11  THRU   15     1.207422E 01    1.112207E 01    5.585083E 01    9.266113E 00    9.246094E 00
    16  THRU   20     4.149561E 01    2.302515E 01    5.553296E 01    4.303027E 01    1.758252E 01
    21  THRU   25     2.562866E 01    2.362622E 01    2.390259E 01    1.719141E 01    2.399365E 01
    26  THRU   30     2.432666E 01    2.452271E 01    2.476343E 01    6.150171E 01    5.555005E 01
    31  THRU   32     2.531055E 01    7.000000E 01

C1     0.27146E 00 C2     0.63797E 00 C22    0.68504E 00 C23    0.54292E 00

C24    0.13010E 02 C25    0.98301E 00 C26    0.95056E 00 C27    0.95056E 00

C28    0.95056E 00 C3     0.44329E 00 C4     0.34300E 01 C5     0.34300E 01

C6     0.16799E 00 G53    0.14670E 01 G62    0.50000E 00

* * * *
TIME  1.50000E 00 DTIMFU  5.00011E-03 CSGMIN(   20)  1.64896E-04 OTMPCC(   20)  1.09204E 00 ARLXCC(    2)  4.54102E-02

     1  THRU    5     7.169604E 01    7.199585E 01    7.584497E 01    1.329297E 01    1.380981E 01
     6  THRU   10     6.366187E 01    6.996973E 01    6.579199E 01    4.961108E 01    1.918896E 01
    11  THRU   15     1.380322E 01    1.520410E 01    6.584961E 01    1.080591E 01    1.076465E 01
    16  THRU   20     8.537085E 01    6.702539E 01    6.095313E 01    4.375244E 01    6.886011E 01
    21  THRU   25     6.898071E 01    6.916748E 01    6.998853E 01    6.856567E 01    7.062769E 01
    26  THRU   30     7.279370E 01    7.379761E 01    7.480981E 01    6.187207E 01    6.492627E 01
    31  THRU   32     7.644653E 01    7.000000E 01

C1     0.27146E 00 C2     0.63797E 00 C22    0.68504E 00 C23    0.54292E 00

C24    0.59456E 00 C25    0.98301E 00 C26    0.95056E 00 C27    0.95056E 00

C28    0.95056E 00 C3     0.44329E 00 C4     0.34300E 01 C5     0.34300E 01

C6     0.16799E 00 G53    0.14670E 01 G62    0.50000E 00

* * * *
TIMF  1.75000E 00 DTIMFU  5.00011E-03 CSGMIN(   20)  1.64896E-04 OTMPCC(    5)  1.79028E 00 ARLXCC(    2)  4.56543E-02

     1  THRU    5     1.198315E 02    1.201404E 02    1.239287E 02    1.580322E 01    3.565161E 01
     6  THRU   10     7.762378E 01    1.158750E 02    1.111938E 02    8.542407E 01    2.565308E 01
    11  THRU   15     1.718994E 01    3.790527E 01    8.028345E 01    1.365674E 01    1.357080E 01
    16  THRU   20     1.339448E 02    1.116008E 02    7.162622E 01    4.506274E 01    1.169668E 02
    21  THRU   25     1.134092E 02    1.172817E 02    1.181296E 02    1.167056E 02    1.187822E 02
    26  THRU   30     1.209724E 02    1.219404E 02    1.229180E 02    5.258994E 01    7.869409E 01
    31  THPU   32     1.246128E 02    7.000000E 01

C1     0.27146E 00 C2     0.63797E 00 C22    0.68504E 00 C23    0.54292E 00

C24    0.59456E 00 C25    0.98301E 00 C26    0.95056E 00 C27    0.95056E 00

C28    0.95056E 00 C3     0.44329E 00 C4     0.34300E 01 C5     0.15675E 00

C6     0.16799E 00 G53    0.14670E 01 G62    0.50000E 00

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